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SPACE TUG SYSTEMS STUDY (CRYOGENIC)
SEPTEMBER DATA DUMP

VOLUME 1 Summary
Program Option 1

SEPTEMBER 1973

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PREPARED FOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
UNDER CONTRACT NO. NAS8-29677

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PREFACE

This study report for the Tug Program is submitted by the McDonnell Douglas Astronautics Company (MDAC) to the Government in partial response to Contract Number NAS8-29677.

The current results of this study contract are reported in eight volumes:

Volume 1 — Summary, Program Option 1

Volume 2 — Summary, Program Option 2

Volume 3 — Summary, Program Option 3

These three summary volumes present the highlights of the comprehensive data base generated by MDAC for evaluating each of the three program options. Each volume summarizes the applicable option configuration definition, Tug performance and capabilities, orbital and ground operations, programmatic and cost considerations, and sensitivity studies. The material contained in these three volumes is further summarized in the Data Dump Overview Briefing Manual.

Volume 4 — Mission Accomplishment. (3 Books and 1 Supplement Bound Together)

This volume contains mission accomplishment analysis for each of the three program options and includes the tug system performance, mission capture, and fleet size analysis.

Volume 5 — Systems (3 Books)

This volume presents the indepth design, analysis, trade study, and sensitivity technical data for each of the configuration options and each of the Tug systems i.e., structures, thermal, avionics, and propulsion. Interface with the Shuttle and Tug payloads for each of the three options is defined.

Volume 6 — Operations (3 Books)

This volume presents the results of orbital and ground operations trades and optimization studies for each option in the form of operations descriptions, time lines, support requirements (GSE, manpower, networks, etc.), and resultant costs.

Volume 7 — Safety (3 Books)

This volume contains safety information and data for the Tug Program. Specific safety design criteria applicable to each option are determined and potential safety hazards common to all options are identified.

Volume 8 — Programmatics and Cost (3 Books)

This volume contains summary material on Tug Program manufacture, facilities, vehicle test, schedules, cost, project management, SR&T, and risk assessment for each option studied.

These volumes contain the data required for the three options which were selected by the Government for this part of the study and are defined as:

A. Option 1 is a direct development program (I.O.C.: Dec 1979). It emphasizes low DDT&E cost; the deployment requirement is 3500 pounds into geosynchronous orbit, it does not have retrieval capability, and it is designed for a 36-hour mission. MDAC has also prepared data for an alternative to Option 1 which deviates from certain requirements to achieve the lowest practicable DDT&E cost.

B. Option 2 is also a direct development program (I.O.C.: 1983). It emphasizes total program cost effectiveness in addition to low DDT&E cost. The deployment requirement is 3500 pounds minimum into geosynchronous orbit and 3500 pounds minimum retrieval from geosynchronous orbit.

C. Option 3 is a phased development program (I.O.C.: 1979 phased to I.O.C. 1983). It emphasizes minimum initial DDT&E cost and low total program cost. The initial Tug capability will deploy a minimum of

3500 pounds into geosynchronous orbit without retrieval capability, however, through phased development, it will acquire the added capability to retrieve 2200 pounds from geosynchronous orbit. The impact of increasing the retrieval capability to 3500 pounds is also provided.

CONTENTS

INTRODUCTION

The Government's evaluation of the Tug concept selection data and recommendations by McDonnell Douglas Astronautics Company (MDAC) presented in July 1973 resulted in a directive to conduct further in-depth analysis and to provide data and conclusions for three selected Cryogenic Tug program options.

The material presented in this Tug program study by MDAC is completely responsive to the negotiated statement of work and subsequent direction. The study results provide a comprehensive data base that can be used in the Government planning studies to select the most attractive Cryogenic Tug program option for comparison with other alternatives under consideration. The Option 1, Direct Development Program (IOC: 1979) study results are summarized in this data package, Volume 1.

The baseline configuration for Option 1 is shown and described in Section 1. This configuration was developed from the design, analysis, and trade studies (technical and programmatic) of viable alternates. The current concept evaluation process has been conducted, and substantiating data for the conclusions and recommendations reached by MDAC are provided herein. Alternates within Option 1 which were evaluated and the reasons for the baseline selection are provided in the detailed supporting documentation contained in Volume 4 - Mission Accomplishment, Volume 5 - Systems, Volume 6 - Operations, Volume 7 - Safety, and Volume 8 - Programmatics and Cost, as well as in the briefing material.

A program overview is included in Section 1 of this volume. It contains the key results of the Option 1 study and a comparison of these key results with results of Option 2 and Option 3 studies.

An alternative to Option 1, which achieves the lowest practicable DDT&E cost but with some deviation from directed requirements, is discussed in the Appendix to this report.

Section 1

PROGRAM DEFINITION AND OBJECTIVES

The Space Tug is a reusable vehicle designed to operate in conjunction with the National Aeronautics and Space Administration's (NASA's) Space Shuttle. The Tug is transported by the Space Shuttle to low Earth orbit, where it then performs as a propulsive stage for placement and retrieval of payloads in higher-energy orbits including synchronous altitudes. When transporting the Tug and payload, the Space Shuttle Orbiter is capable of deploying 65,000 lb to a 160-nmi circular orbit. The Orbiter also retrieves the Tug after it performs its mission from a similar orbit for return to Earth. For the purpose of this system study, the Tug is to be a cryogenic propulsive stage that uses liquid hydrogen and liquid oxygen as propellants.

Cryogenic Tug Option 1 is a direct development program that is to provide an initial operation capability (IOC) on December 31, 1979. In developing the complete description of this program option, the following were to be given the principal emphasis while achieving a Tug at a low program cost, low risk, and high reliability:

- Minimum (low) design, development, test, and evaluation (DDT&E) costs
- No planned growth capability
- Minimum performance, place $\geq$3,500 lb to geosynchronous orbit
- Deploy payloads only, no rendezvous and docking ability
- 36-hour mission duration limit
- No power to payload, meet other minimum payload requirements.

Additional ground rules assumed for this option are as follows:

- No payload spin-up capability
- Payload interface diameter fixed
- No payload checkout capability.

Within the Option 1 capability, three specific sensitivities were to be investigated:

A. Programmatic sensitivity for two-year-later IOC (December 31, 1981)

B. DDT&E effects for greater than 36 hours of mission duration

C. Impact to provide 300 watts to payload.

The physical and performance characteristics of Option 1 are shown in Table 1.

Table 1

PROGRAM OPTION 1

Capability Option: Direct Developed-Deploy Only — IOC Date April 1, 1980

Program Objective: Lowest DDT&E Cost to Deploy 3,500 lb to Geosynchronous Orbit

Physical Characteristics		Program Characteristics	
Main Engine Type	CAT I RL10	Autonomy level	IV
Mixture ratio	5.5:1	Development time (to IOC)	54 Mo
Thrust	15,000 Lb	Mission completion probability**	0.983/0.973
ISP	441.8 Sec	Fleet size	13
APS type	Blow Down Mono	Number of flights (ETR/WTR)	193/32
ISP	215 Sec	Reusable (ETR/WTR)	185/32
Weight Summary		Expendable (ETR/WTR)	8/0
Burn-out weight	7,340 Lb	Ground turnaround time***	19.6/19.1
Gross weight (less payload)	59,334 Lb	Cost Summary (1973 $ Millions)	
Usable propellant	51,342 Lb	Program cost	577.43
*Stage mass fraction (λ')	0.865	DDT&E cost	197.05
Performance Summary		Peak year funding	76.7/FY '78
Payload deployed (geosync)	3,520 Lb	Operations cost/flight (avg)	0.90
Payload retrieved (geosync)	----	First-unit cost	14.44
Payload round trip (geosync)	990 Lb	SR&T cost	0.84
Structural configuration	Load-Carrying Tank		
Stage length	32.8 ft		

*λ' = Total usable capacity/gross weight (less payload)
**1.5 day mission/with kick stage
***Working days (ETR/WTR)

1.1 TUG PROGRAM OVERVIEW

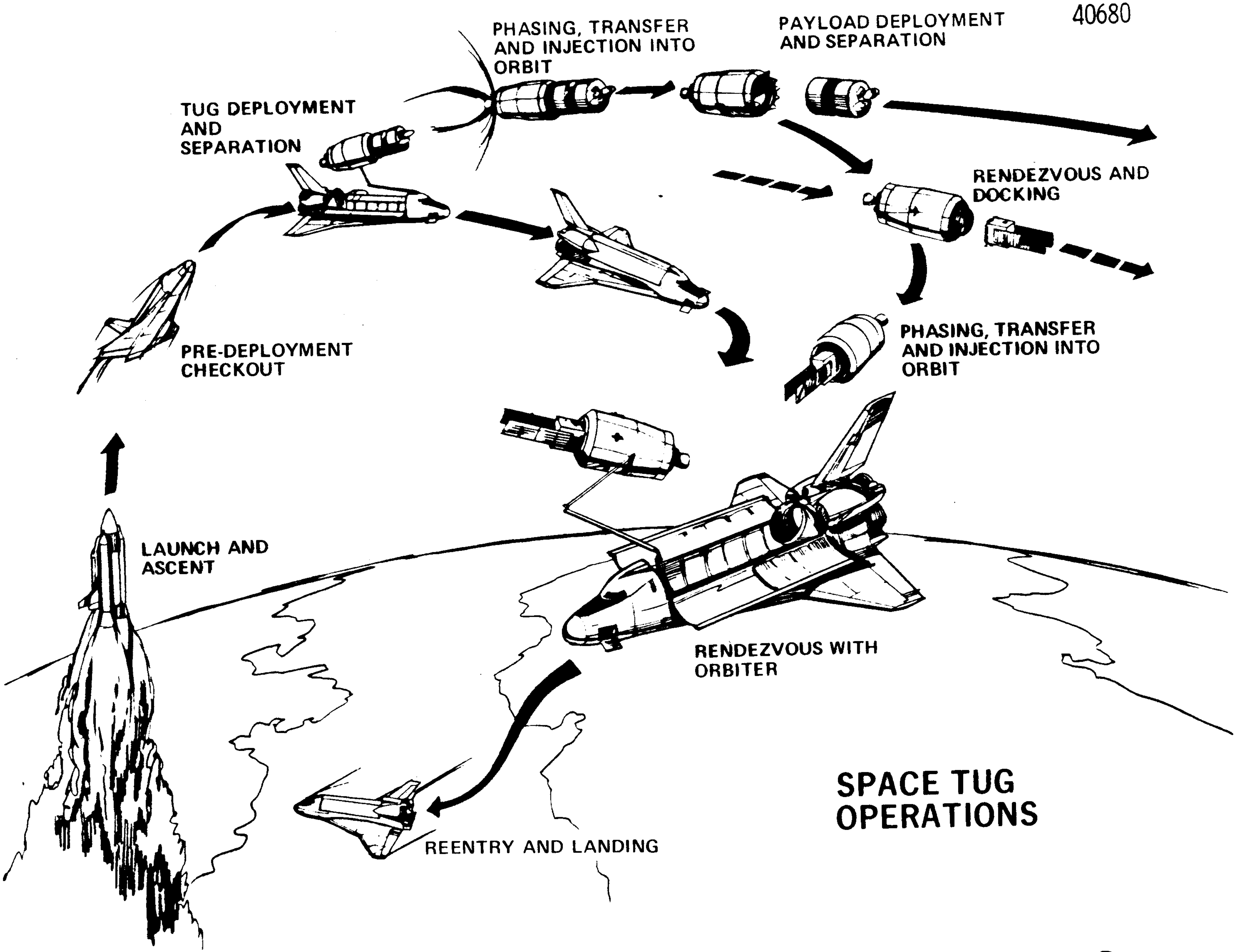
Each of the three tug options is discussed in a separate volume dedicated to the individual option being summarized. For the convenience of the reader, this section contains a brief program overview which presents the highlight features of all three options. Comparative data should be used with the awareness that the mission model is different for each of the options.

The following figures are individually discussed in subsequent pages.

Figure 1 -1 Space Tug Operations
-2 Key Issues
-3 Space Tug Program Options
-4 Mission Model Comparison
-5 Performance Comparison
-6 Cost Comparison
-7 Space Tug Program Option Summary Comparison

SPACE TUG OPERATIONS

This study encompasses all aspects of the Space Tug operations. Depicted on the chart is the different phases of flight operations from liftoff until landing. Included is the deployment of the Tug from the Shuttle cargo bay at 160 nmi and the rendezvous of a Tug and its retrieved payload with the Orbiter before reentry and landing. Ground operations were also studied extensively.



SPACE TUG OPERATIONS

KEY ISSUES

Since the Tug flies with the Orbiter during ascent and return to Earth it must meet the safety standards for a manned space vehicle during these times. For performance and capability it must at least meet the minimum requirements specified by the Government. In all operations minimum DDT&E costs are important. However, DDT&E costs should not be lowered to the point that the operations cost, for the life of the vehicle, will be prohibitive. In addition to minimum DDT&E and operations cost, low peak year funding is desirable, especially through the 1975 to 1978 time period.

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KEY ISSUES

- MEET SAFETY STANDARDS
- MEET PERFORMANCE/CAPABILITY REQUIREMENTS

- MINIMIZE DDT&E COSTS
- MINIMIZE PEAK YEAR FUNDING
- DRIVE OPERATIONS COSTS DOWN

SPACE TUG PROGRAM OPTIONS

The three options indicated were those provided by the Government. The deployment and retrieval requirements are minimum for each option. Numerous sensitivity studies were conducted for each of the options and include varying the IOC data and assessment of program impacts.

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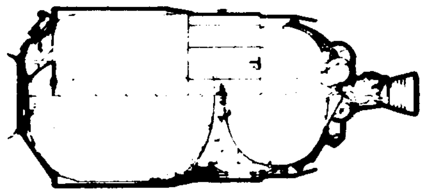
SPACE TUG PROGRAM OPTIONS

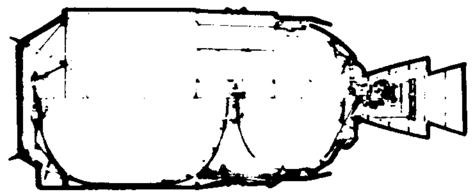
✓ OPTION 1.
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- NO RETRIEVAL CAPABILITY
- 36 HOUR MISSION

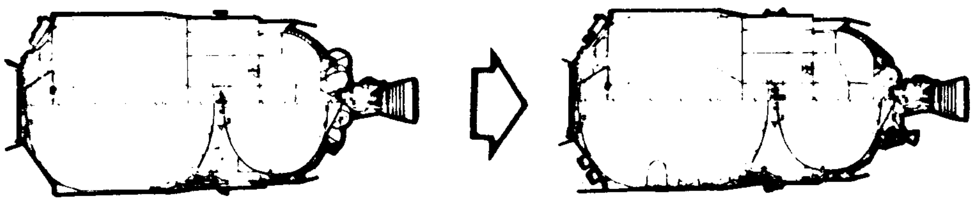
OPTION 2.
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1983

- TOTAL PROGRAM COST EFFECTIVENESS
- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- RETRIEVE 3500 LB (GEOSYNCHRONOUS)

OPTION 3.
PHASED DEVELOPMENT PROGRAM



IOC: DEC 1979 DEC 1983

- MINIMIZE INITIAL DDT&E
- LOW TOTAL PROGRAM COST
- INITIAL:
  DEPLOY 3500 LB (GEOSYNCHRONOUS)
  NO RETRIEVAL CAPABILITY
- FINAL:
  DEPLOY 3500 LB (GEOSYNCHRONOUS)
  RETRIEVE 2200 LB (GEOSYNCHRONOUS)

MISSION MODEL COMPARISON

The mission models provided by the Government for each option different in number and types of missions and the weights of the payloads involved. As a result of these necessary differences, care must be taken in comparing one option to another. For example, in each option, the time of operation is from IOC to 1990 resulting in different program durations. The mission model for Option 1 contains 360 deployment missions and 4 sortie missions over an eleven year period (1980 through 1990). The payload weights were all "current design" weights; the minimum in the total mission model. Of the total, 270 are geosynchronous or high altitude, 22 interplanetary and 68 low orbit missions.

Option 2 has the heaviest payloads (using some of the low cost payload weights from the total mission model) and the most missions per year however the later IOC (December 1983) results in only a seven year duration. The mission model includes retrieval missions as well as deployment missions. In addition, multiple deployment missions require a positional separation of 60° between payloads whereas the Option 1 model allowed deployment of multiple payloads at one orbital location. The Option 2 model contains 437 missions (258 deployments and 179 retrievals) of which 328 are geosynchronous or high altitude, 19 are interplanetary and 90 are low orbit missions.

The Option 3 mission model is quite similar to the Option 2 model except for the earlier IOC (December 1979) the elimination of the retrieval mission for NASA mission 5 and its decreased weight. For the years prior to 1984 (the final configuration IOC date) the model is like the Option 1 model for those years except for the increased payload weights. Out of 558 missions (387 deployments and 171 retrievals), 430 are geosynchronous or high orbits, 22 interplanetary, and 106 low orbit missions.

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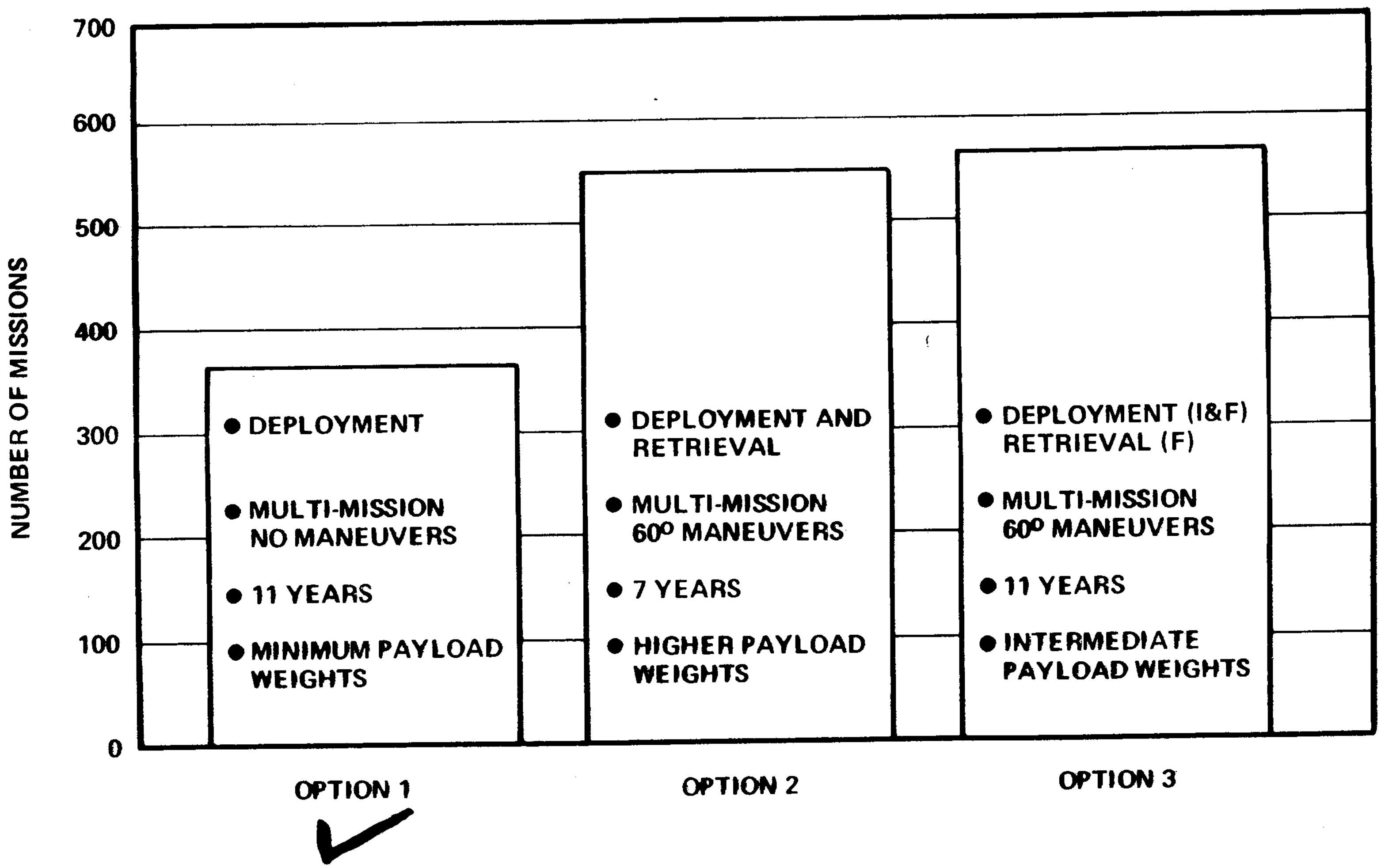
MISSION MODEL COMPARISON



OPTION COMPARISON—PERFORMANCE

This chart compares the performance of the vehicle studies for each of the three options. In the case of Option 2 it was possible to use higher technology in this vehicle because of the 1983 IOC date. Consequently, its deployment, retrieval and round trip capability far exceeds the other options. It uses a Category II RL10 engine and the other vehicles have Category I RL10 engines. The final vehicle for Option 3 could be made into a vehicle with performance similar to Option 2 if the Category II RL10 engine were used instead of the Category I. The deployment capability of the Option 3 Initial vehicle and that of Option 1 are very close.

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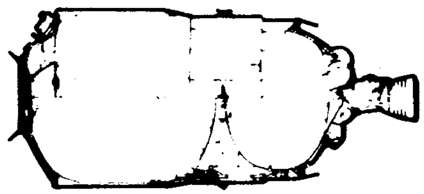
OPTION COMPARISON

PERFORMANCE

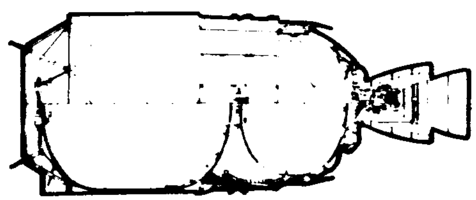
OPTION 1
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

- DEPLOY – 3,521
- RETRIEVE – NONE
- ROUND TRIP – 993

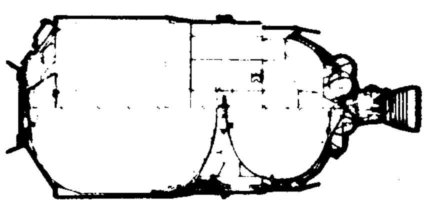
OPTION 2
DIRECT DEVELOPMENT PROGRAM



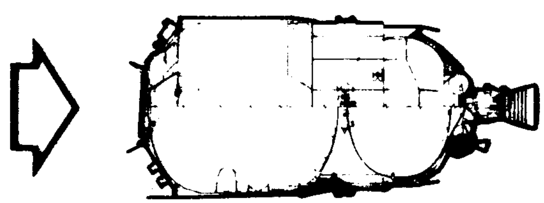
IOC: DEC 1983

- DEPLOY – 7,640
- RETRIEVE – 4,814
- ROUND TRIP – 2,953

OPTION 3
PHASED DEVELOPMENT PROGRAM



IOC: DEC 1979



DEC 1983

		INITIAL	FINAL
● DEPLOY	–	3,588	4,330
● RETRIEVE	–	NONE	2,567
● ROUND TRIP	–	1,335	1,611

OPTION COMPARISON — COST

This chart provides a cost comparison breakdown of the different options. The costs which are strongly dependent on the mission model are specifically identified. Since the mission model must vary between options (i.e., Retrieval vs Deploy only), care must be taken when comparing these costs.

An interesting comparison is the DDT&E cost for Option 1 and the DDT&E cost for the Initial Option 3. It should be noted that the initial phase of Option 3 is less costly than Option 1 because some of the initial GSE costs for Option 3 have been deferred to final phase. This is possible because of the limited initial fleet size. However, from a peak funding view, the initial phase of Option 3 and Option 1 are identical and peak in 1978 at 79.7 million. The total DDT&E for Option 3 is same 80 million over Option 1 which provides the required development for the required additional capability, e.g., Retrieval, 6 days, etc. The final phase of Option 3 peaks at 90.2 million in 1981. The advantages of the Option 3 over Option 1 is that a phasable vehicle can be provided with no initial DDT&E penalty.

The higher Option 2 DDT&E cost is expected with this higher capability Tug. The peak year funding of Option 2 occurs in 1982 consistent with the December 1983 IOC.

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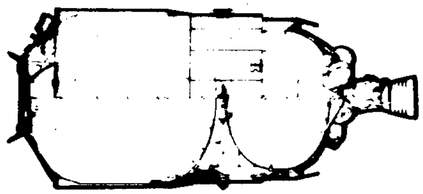
OPTION COMPARISON

COST (IN MILLIONS OF DOLLARS)

OPTION 1
DIRECT DEVELOPMENT PROGRAM

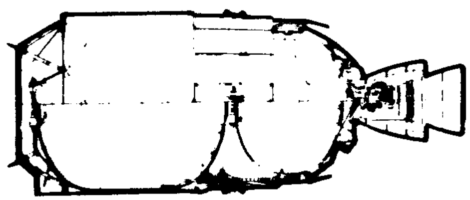
✓



IOC: DEC 1979

• DDT&E	–	$197.1
• PEAK YEAR	–	76.7
• COST/FLT	–	0.90
• FIRST UNIT COST	–	14.4
• OPERATIONS	–	200.8
• PRODUCTIONS	–	179.6
• TOTAL PROGRAM	–	577.4

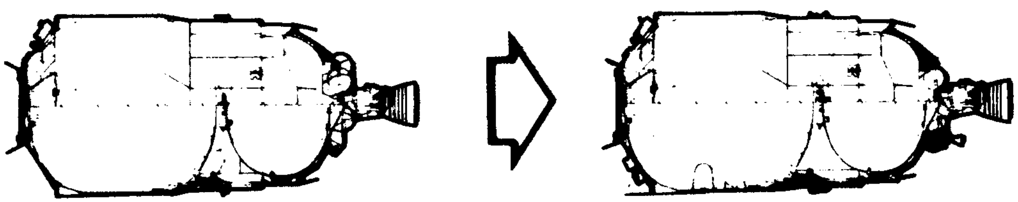
OPTION 2
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1983

• DDT&E	–	$298.8
• PEAK YEAR	–	124
• COST/FLT	–	0.76
• FIRST UNIT COST	–	18.1
• OPERATIONS	–	169.4
• PRODUCTION	–	214.3
• TOTAL PROGRAM	–	682.5

OPTION 3
PHASED DEVELOPMENT PROGRAM



IOC: DEC 1979 DEC 1983

		INITIAL	FINAL
• DDT&E	–	190.1	88.8
• PEAK YEAR	–	76.7	90.2
• COST/FLT	–	1.07	0.71
• FIRST UNIT COST	–	14.7	17.4
• OPERATIONS			
• OPERATIONS	–	88.6	204.5
• PRODUCTION	–	98.6	176.8
• TOTAL PROGRAM	–	377.3	470.1

• MISSION MODEL DEPENDENT

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SPACE TUG PROGRAM OPTION SUMMARY

CONFIGURATION DATA

OPTION NO.	1	1A	2	3I	3F	3S
MAIN ENGINE	CAT I RL-10	CAT. I RL-10	CAT 2A RL 10	CAT I RL 10	CAT I RL 10	CAT 2A RL 10
MIXTURE RATIO (EMR)	5.5:1	5.5:1	6:1	5.5:1	5.5:1	6:1
ISP	441.8	441.8	458.2	441.8	441.8	458.2
THRUST	15K →	→	→	→	→	→
PRESSURIZATION	AMB He	AMB He	ZNPSH	AMB He	COLD-HEATED He	ZNPSH
APS	MONO B/D	MONO B/D	BI-PROP	MONO B/D	BI-PROP	BI-PROP
PROPELLANT UTILIZATION	CLOSED LOOP →	→	→	→	→	→
PNEUMATIC BOTTLES	SIVB TITAN →	→	→	→	→	→
STRUCTURE CONFIGURATION	LCT	LCT	LCS	LCT	LCT	LCT
SHELL CONST AND MATERIAL	OPEN AL-ISO →	→	GF/AL H'COMB'	OPEN AL-ISO →	→	→
TANK CONSTRUCTION	AL ISO-G	AL ISO-G		AL ISO-G	AL ISO-6	AL ISO-6
TANK MATERIAL/DOME	2219 TAPER →	→	→	→	→	→
TANKAGE	2219 ISU →	→	2219 MONO	2219 ISU →	→	→
PL SIDEWALL STRUCTURE	LATCH ONLY	EXP BOLTS	MAN ADJ	LATCH ONLY	MAN ADJ →	→
INSULATION	REF →	→	MLI	REF	MLI →	→
EQUIP THERMAL CONT	H-PIPE PANEL →	→	→	→	→	→
THRUST STRUCTURE	Ti ISO →	→	FG ISO →	→	→	→
TANK SUPPORTS	Ti TUBE →	→	FG TUBE →	→	→	→
POWER SYSTEM	BATT	BATT	ADV-FCP	BATT	ADV-FCP →	→
RENDEZVOUS CONCEPT	NONE →	→	LASER	NONE	LASER →	→
GUIDANCE, NAV AND CONTROL	IMU ST →	→	→	→	→	→
DATA MANAGEMENT	1-CENT 2 RP →	→	2-CENT	1-CENT 2 RP	2-CENT 2 RP →	→
ONBOARD CHECKOUT	LRU S/O →	→	→	→	→	→
AUTONOMY LEVEL	IV	IV	III	IV	III	III
PAYLOAD CHECKOUT	NONE →	→	T/M RELAY	NONE	T/M RELAY →	→

PROGRAMMATIC DATA

OPTION NO.	1	1A	2	3I	3F	3S
DESCRIPTION	INTERIM DIR DEV	INTERIM LOW COST	DELAYED DIR DEV	PHASED INITIAL	PHASED FINAL	PHASED/ HI PERF
IOC DATE	DEC 79	DEC 79	DEC 83	DEC 79	DEC 83	DEC 83
MULTI-MISSION CAP.	YES →	→	→	→	→	→
PL SPIN UP CAPABILITY	NO →	→	YES	NO	YES →	→
PL POWER PROVISIONS	0	0	300	0	300	300
MISSION DURATION	1 1/2 DAY	1 1/2 DAY	6 DAY	1 1/2 DAY	6 DAY	6 DAY
PAYLOAD DEP (SYNC)	3,521	2,971	7,640	3,531	4,350	8,732
PAYLOAD RET (SYNC)	–	–	4,814	–	2,465	4,135
PAYLOAD RT (SYNC)	903	870	2,863	1,325	1,827	2,630
BURNOUT WEIGHT	7,340	7,555	8,430	7,470	7,180	8,974
GROSS WEIGHT (LESS P/L)	59,334	58,540	63,120	59,335	63,120	63,106
USABLE PROPELLANT	51,342	51,342	55,932	51,212	54,861	56,027
MASS FRACTION	0.865	0.862	0.880	0.863	0.866	0.872
DDT&E $ MILLIONS	197.05	177.01	298.77	190.1	88.8	
OPERATIONS $ MILLIONS	200.81	–	189.44	88.6	204.5	
PRODUCTION $ MILLIONS	179.57	–	214.29	92.6	178.8	
TOTAL PROGRAM $ MILLIONS	577.43	–	802.50	377.3	470.1	
FLEET SIZE	13	–	12	5	11	10
PEAK FUNDING/YR $ MILLIONS	76.7/78	–	124/82	76.7/78	90.2/81	
MAIN STAGE (1ST UNIT) $ MILLIONS	14.44	–	18.08	16.03	17.4	
MAIN STAGE (AVG) $ MILLIONS	12.22	–	16.41	14.7	15.50	
KICK STAGE $ MILLIONS	2.30	–	3.47	6.15	0.91	
COST/FLT $ MILLIONS						
MODE 1 (REUSE)	0.90	–	0.76	1.07	0.71	
MODE 2 (EXPENDED)	12.89	–	16.76	17.3	16.0	
MODE 3 (W KICK STAGE)	3.20	–	4.23	6.2	1.8	
SR&T $ MILLIONS	0.84	0.84	15.44	0.84 →	13.99T	13.99T

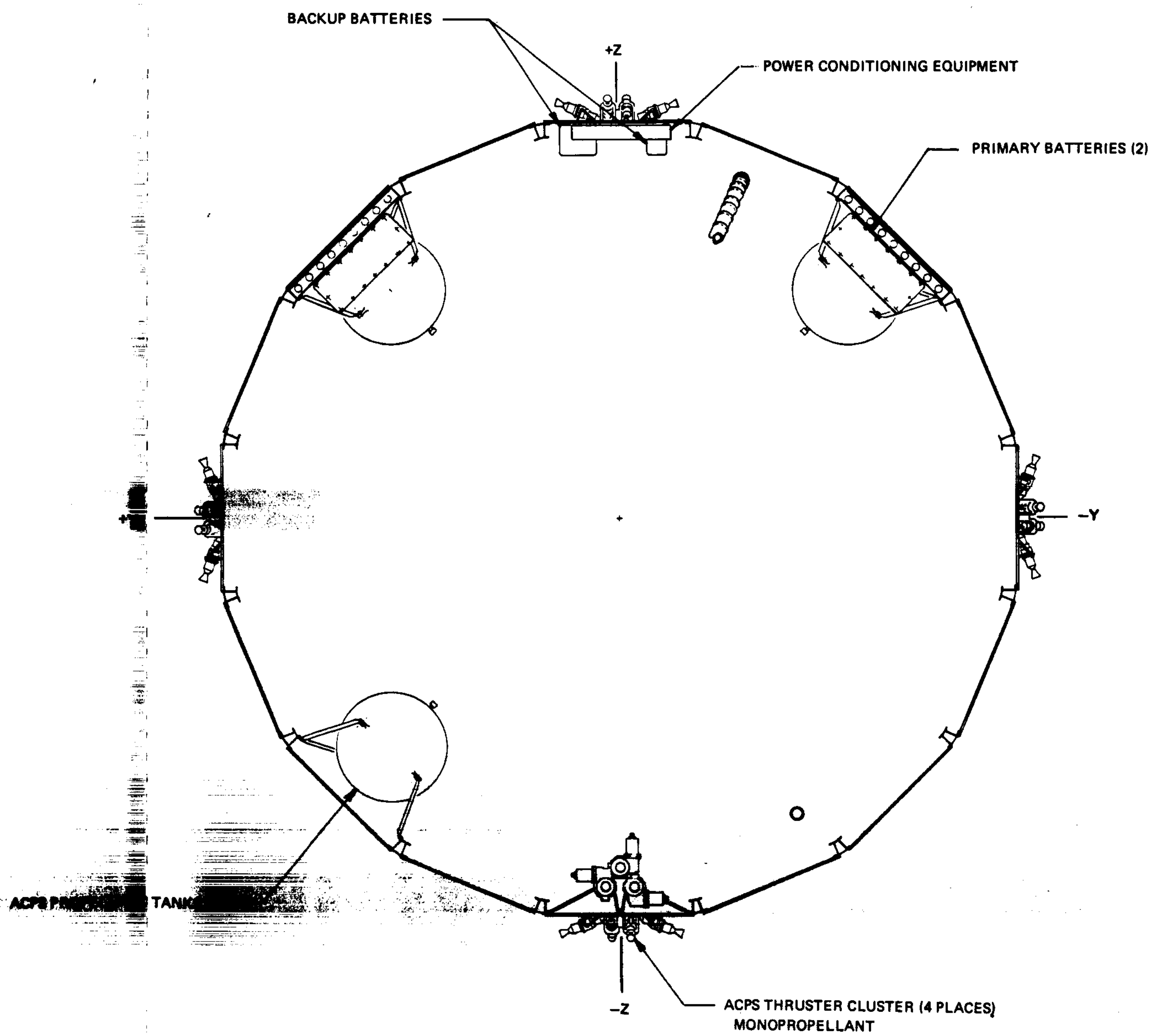
Section 2
CONFIGURATION DEFINITION

2.1 SPACE TUG VEHICLE MAIN STAGE (WBS 320-03)

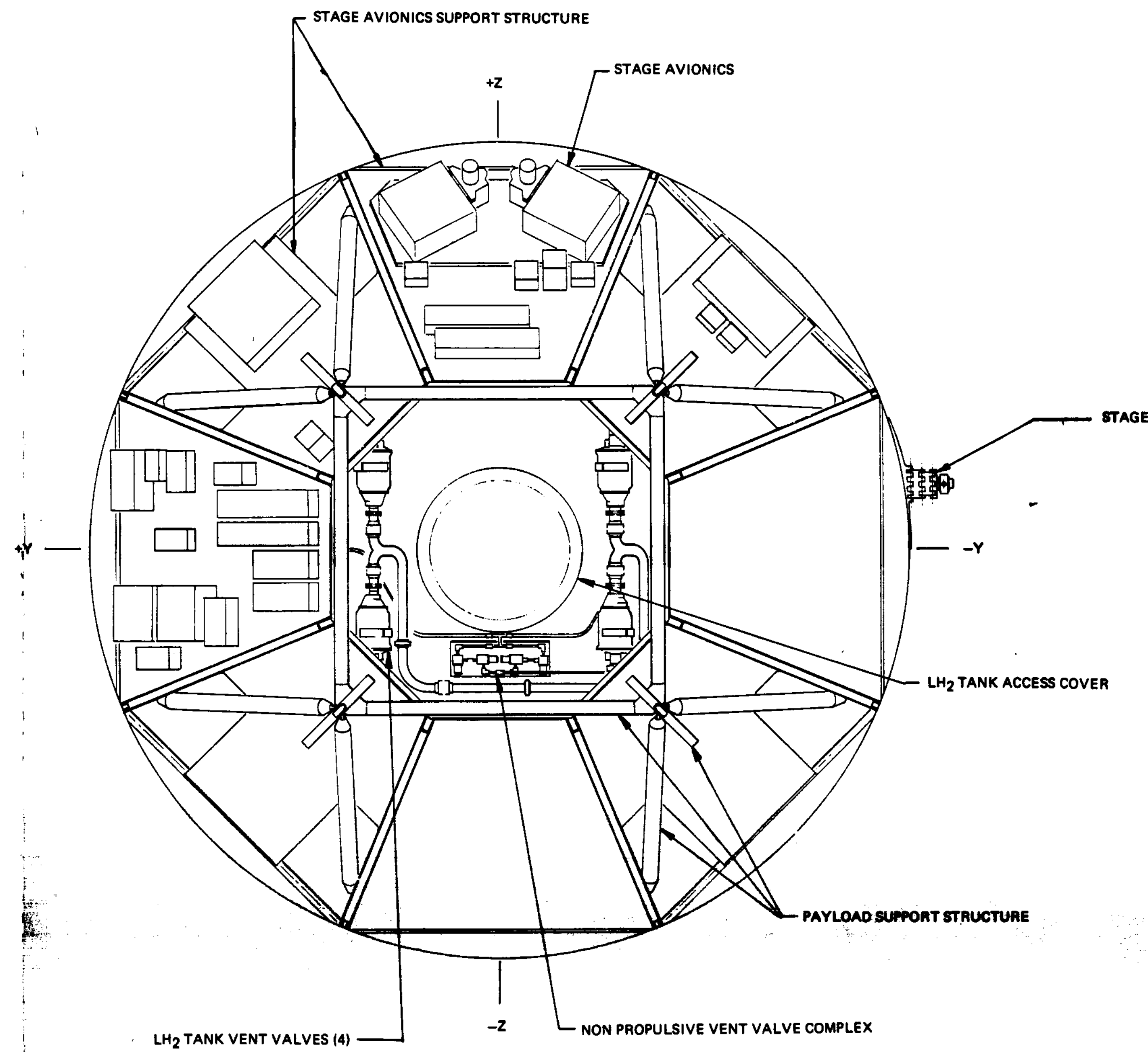
The Cryogenic Tug Option 1 will contain 51,342 lb of usable LH_2 and LO_2 propellants for operation of its Category I RL-10 main engine. The configuration (see Figure 2-1) consists of primary structure, thermal control provisions, avionics and propulsion subsystems, and Shuttle and payload interface accommodations. The vehicle has an overall diameter of 176 in. (14.7 ft) and a total length without payload of 389.8 in. (32.5 ft). The stage dry weight and gross weight less payload are 6,454 lb and 59,334 lb, respectively.

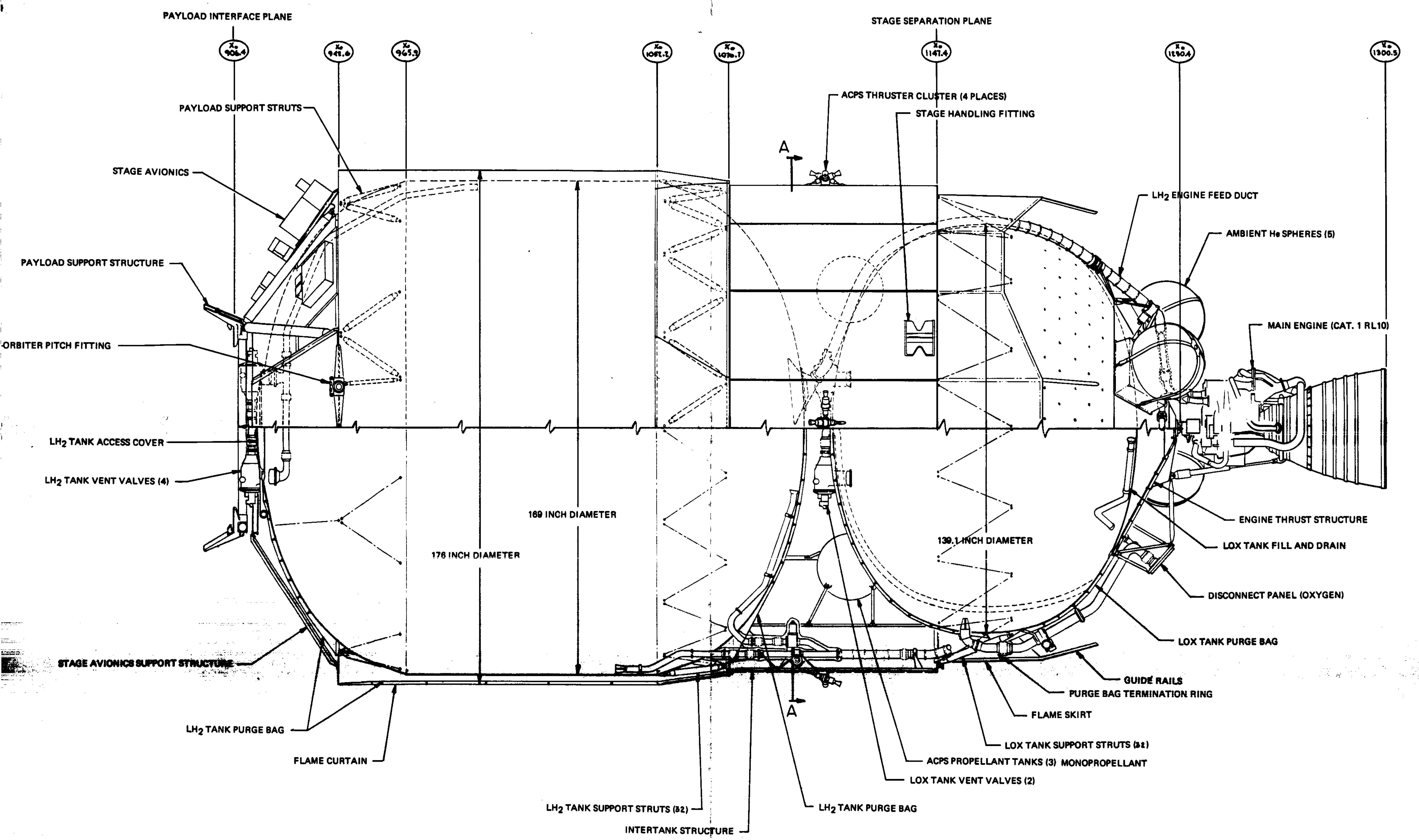
2.2 STRUCTURES SUBSYSTEM SUMMARY (WBS 320-03-01)

The structural concept is designed to meet the program requirements established for Option 1, as discussed in Section 1. Figure 2-2 identifies the primary structural elements of this low-cost vehicle. Table 2-1 provides the structural materials used. For basic vehicle structure, the primary impact of the option goal of low DDT&E expenditures is reflected in simplicity of materials, mechanisms, and processes, and in minimum test requirements. The load-carrying tank (LCT) arrangement incorporates an isogrid-stiffened 2219 aluminum fuel tank sidewall. The forward end of the tank is attached to the forward support frame, and the aft end is attached to the constant section intertank shell. Eight titanium trusses are used to attach to the forward end of the tank cylinder at 16 equally spaced points. The trusses tie to the forward support frame at eight hard points where the payload support trusses and the avionics support panel joints attach, providing good load-path continuity. This forward titanium frame also reacts the stage-support pitch loads with a pivoted fitting on the side of the stage. The avionics mounting panel is an aluminum isogrid with integrally machined heat-sink panels for component mounting and heat conduction to the attached heat pipes.


BACKUP BATTERIES
+Z
POWER CONDITIONING EQUIPMENT
PRIMARY BATTERIES (2)
+Y
-Y
-Z
ACPS THRUSTER CLUSTER (4 PLACES)
MONOPROPELLANT

SECTION A-A


STAGE AVIONICS SUPPORT STRUCTURE
+Z
STAGE AVIONICS
STAGE
+Y
-Y
LH_2 TANK ACCESS COVER
PAYLOAD SUPPORT STRUCTURE
-Z
LH_2 TANK VENT VALVES (4)
NON PROPULSIVE VENT VALVE COMPLEX



PAYLOAD INTERFACE PLANE
STAGE SEPARATION PLANE
X_o 906.4
X_o 1147.4
X_o 1300.5
PAYLOAD SUPPORT STRUTS
ACPS THRUSTER CLUSTER (4 PLACES)
STAGE HANDLING FITTING
STAGE AVIONICS
A
LH_2 ENGINE FEED DUCT
AMBIENT He SPHERES (5)
PAYLOAD SUPPORT STRUCTURE
MAIN ENGINE (CAT. 1 RL10)
ORBITER PITCH FITTING
LH_2 TANK ACCESS COVER
LH_2 TANK VENT VALVES (4)
169 INCH DIAMETER
176 INCH DIAMETER
139.1 INCH DIAMETER
ENGINE THRUST STRUCTURE
LOX TANK FILL AND DRAIN
DISCONNECT PANEL (OXYGEN)
LOX TANK PURGE BAG
STAGE AVIONICS SUPPORT STRUCTURE
GUIDE RAILS
PURGE BAG TERMINATION RING
FLAME SKIRT
LH_2 TANK PURGE BAG
FLAME CURTAIN
LOX TANK SUPPORT STRUTS (32)
ACPS PROPELLANT TANKS (3) MONOPROPELLANT
LOX TANK VENT VALVES (2)
LH_2 TANK SUPPORT STRUTS (32)
LH_2 TANK PURGE BAG
INTERTANK STRUCTURE

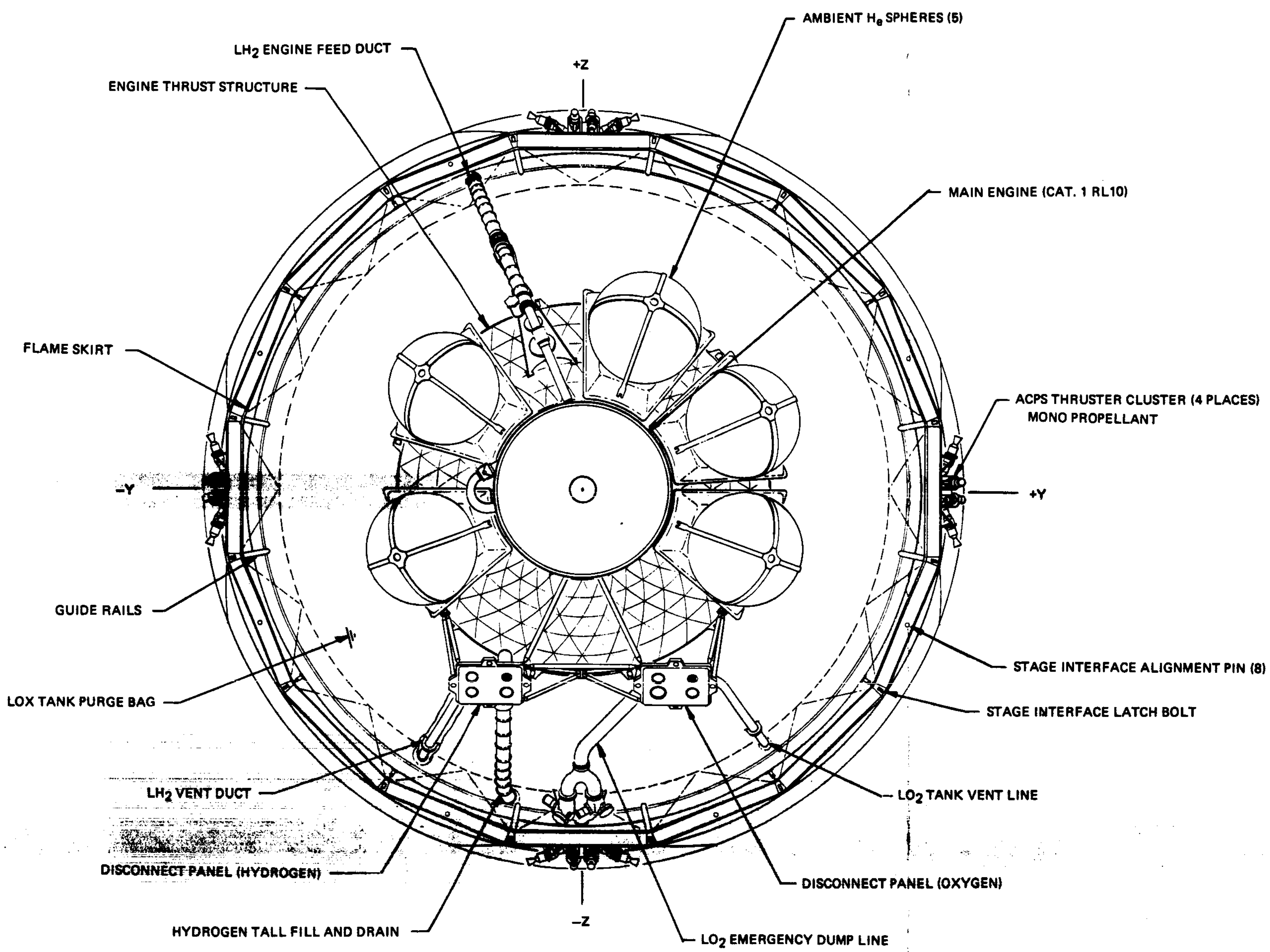


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FIG 2-1

CONTRACT NO.	
PREPARED	7-5-73
CHECKED	
DESIGN ACTIVITY APPROVAL	
CUSTOMER APPROVAL	
INBOARD PROFILE OPTION NO. 1	
CODE IDENT NO. 18355	DRAWING NO. SK-TUG-5-01
SCALE	SHEET 1 OF

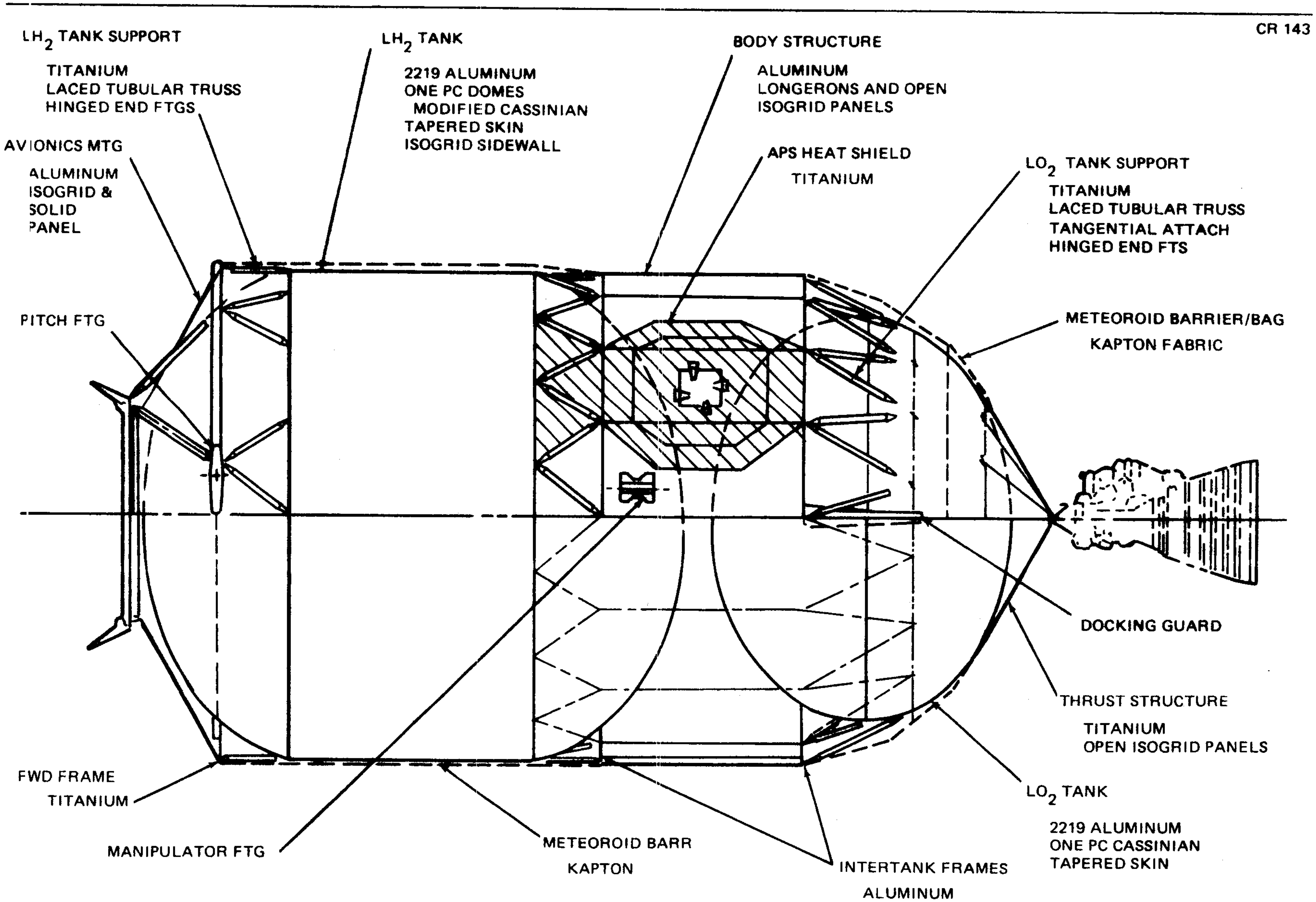


Figure 2-2. Subsystem Structure

Table 2-1

ARRANGEMENT: LOAD-CARRYING TANK

LH_2 Tank:	2219 Al-isogrid cylinder - 1 pc tapered modified cass domes
LO_2 Tank:	2219 Al - 1 pc tapered cassinian domes
Tank Supports:	Hinged 6 Al-4V titanium tubes
	Attached at LH_2 dome/cylinder joint
	Tangentially attached to LO_2 domes
Body Structure:	Load-carrying tank/supports forward
	7075 Al longerons/open isogrid panels midtank
Thrust Structure:	Open isogrid 6 Al-4V titanium panels
Meteoroid Barrier:	Fabric bag

The aft end of the fuel-tank cylinder is attached with 16 laced tubular titanium trusses which carry the body structure loads from 32 points on the tank to 16 longeron locations on the intertank shell at a field joint frame. These square-tube section aluminum longerons carry the concentrated axial and bending loads to the stage-support separation plane at the aft end of the shell. Longeron stability and torsional and bending shear capability are provided by open aluminum isogrid panels. These panels are attached to the longerons and to the aluminum frames at both the forward field joint and the aft separation plane. The panels are all shear-carrying, and alternately fixed and hinged to accommodate component mounting and access. All panels are flat for simplicity of manufacture and mounting.

The oxidizer tank is supported by laced tubular trusses which attach tangentially to pads located below the tank equatorial plane and to the stage-separation plane frame. Fuel-tank supports attach to the tank cylinder-dome intersection where the tank-dome shape transitions to a local cone to provide attachment clearance. All supports are hinged to eliminate radial constraint on the tank. The tank cylinder is extended approximately 12-1/2 in. at each end from a tangential joint location to intersect with the 70-deg half-angle conic dome.

Domes of both tanks are fabricated in one piece of tapered 2219 aluminum. Meridonal weldments are not required, and only single circumferential welds are used at the dome joints. No ring inserts are required. Doors are provided at the forward end of the LH_2 tank and aft end of the LO_2 tank domes for access to internal stores and lines.

Engine thrust is carried into the aft dome of the LO_2 tank by an open isogrid titanium thrust structure. This structure is assembled from 12 similar flat panels jointed at their edges. Local cutouts in the panels are provided for line routing. Attachment to the tank is provided at the 12 corner joints. The flat panels incorporate nodal-point attachment provisions at the isogrid triangle intersections. This provides standard mounting locations for component attachment.

Meteoroid protection for the short mission duration can be provided by a 6-mil fabric cover over the sidewall of the fuel tank and across the end domes of the tanks. This fabric also serves as the reflective insulation system purge bag. The meteoroid barrier provides in excess of an 0.995 probability of no unacceptable tank damage during any mission.

Structural analysis and trade studies are discussed in detail in Volume 5.

2.3 THERMAL CONTROL SUBSYSTEM SUMMARY (WBS 320-03-02)

The thermal control system concept is designed to meet the program requirements established for Option 1. The thermal control of the fuel tank is accomplished with a radiation barrier consisting of a low-emissivity surface (vapor deposited aluminum) on the inside of the Kapton bag which envelops the tank, and a highly reflective sheet of double aluminized Mylar (DAM) on the tank. These are shown in Figures 2-2 and 2-3. Cylindrical pin standoffs prevent the bag from contacting the DAM reflector. Several layers of a Dacron net separate the DAM reflector from the tank surface to reduce convection heat transfer and the potential for liquefying nitrogen on the exterior surface of the bag during ground hold.

Thermal control of the oxidizer tank is accomplished with a system identical to that for the fuel tank except the layers of Dacron net are not needed on the oxidizer tank.

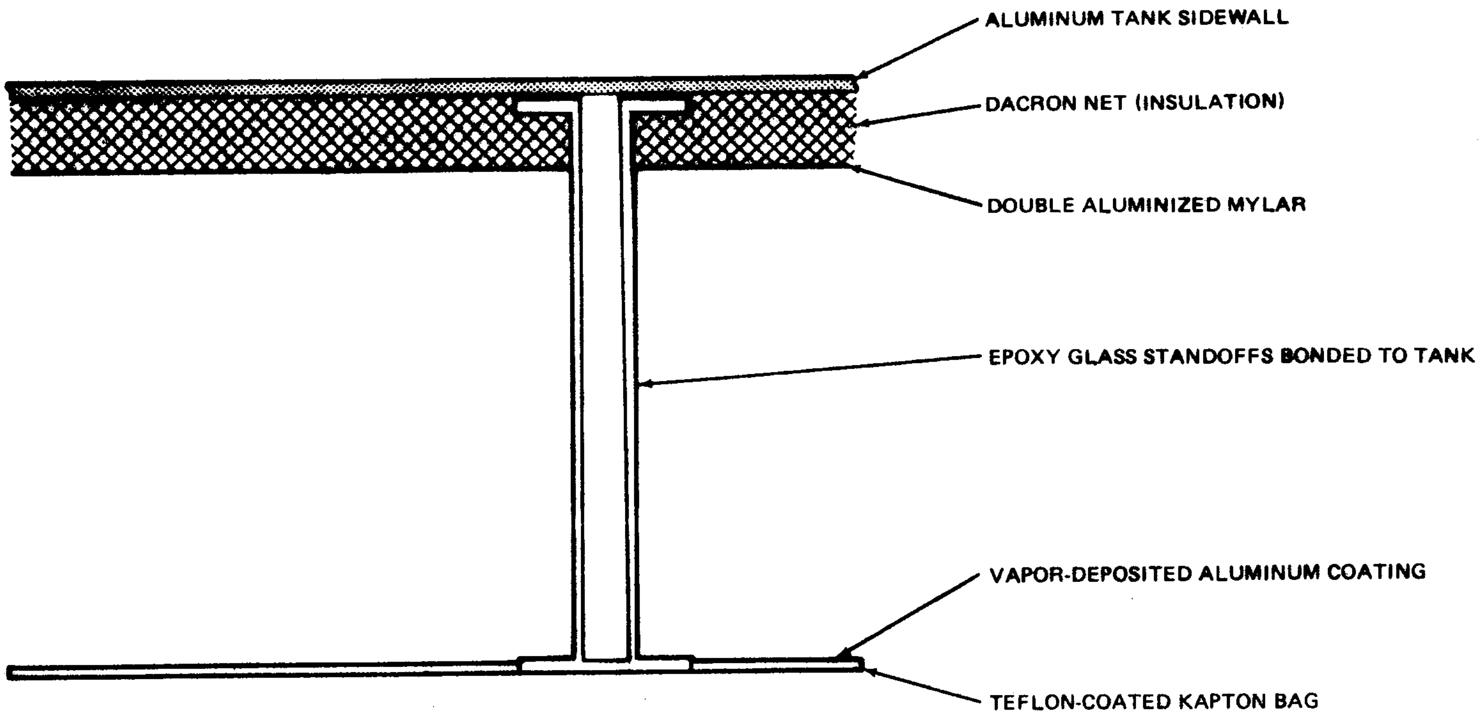


Figure 2-3. LH_2 Tank Insulation System

Separate bags envelop each of the tanks. These bags ensure the presence of gases which will not liquefy or freeze on the tank exterior nor within the insulation system during ground hold, ascent, and reentry. Helium is used for both the preflight purging and the reentry repressurization of the bag. Large valves are used to allow a rapid evacuation of the purge gases during ascent. Pressure controllers are used to control the repressurization of the bags during reentry. A schematic of the purge system is shown in Figure 2-4.

Minimum cost for the thermal control concept is achieved through system simplicity.

Thermal analysis and studies are discussed in detail in Volume 5.

2.4 AVIONICS SUBSYSTEM SUMMARY (WBS 320-03-03)

The avionics system is designed to meet the program requirements established for Option 1.

In order to minimize DDT&E costs, existing avionics have been used to the greatest extent possible and redundancy has been eliminated where possible in those areas affecting DDT&E cost. In some cases, a weight penalty or unit cost penalty was incurred to minimize initial DDT&E cost (e.g., power source/inertial measurement unit selection). Table 2-2 presents a summary of the avionics subsystem characteristics. A block diagram of the subsystem is shown in Figure 2-5.

The data management subsystem consists of a single central computer with a redundant data distribution system and redundant remote data processors. The use of a single central computer eliminates the need for a complex redundancy management scheme at the computer level. The data distribution system consists of two time-multiplexed data paths that route data from redundant interface units to the central computer. The interface units are modular in design, each consisting of a combination of standard interface modules. The remote data processors will provide the required vehicle safing in case of central

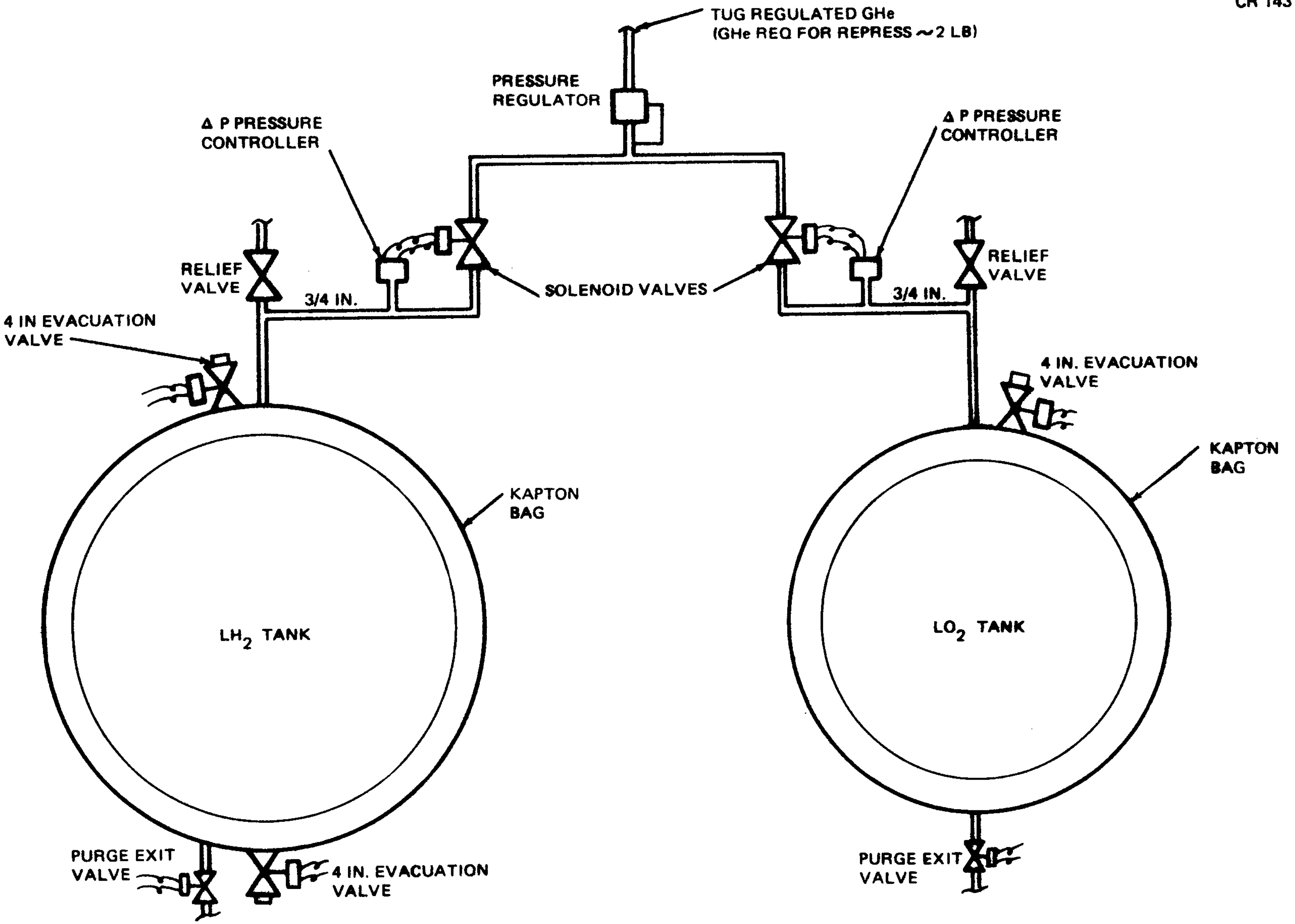


Figure 2-4. Purge, Evacuation, and Repressurization System Schematic

Table 2-2

MAJOR SUBSYSTEM CHARACTERISTICS

Subsystem	Qty	Weight (lb)	Power (W)	Major Subsystem Characteristics Description
Data Management Subsystem (DMS)				• Central computer – 16-bit word length; 16,000 word memory; 2.6-μsec add time
Central Computer	1	12	35	• Remote data processors – 2 required – 16-bit word length; 8,000 word memory; 2.6-μsec add time
Remote Data Processor	2	20	64	• 1-m bit data bus
Data Control Unit	1	8	12	• RDP's provide backup safety control
Modular Interface Units				• Computers are MOS-LSI with plated wire memory
BIU	10	28	95	• PCU – electronic circuit breaker controls 16 power channels
PCU	14	37.4	42	• DIU – Serial digital interface between CMD/TLM bus and LRU's
DIU	2	5.1	3.2	• RMU – remote multiplexer accepts any combination of bilevel or analog input signals for 64 channels
RMU	16	46.8	52.8	• DCU – low-power switch controls up to 32 logic channels
DCU	16	42.8	25.6	• SCU – provides amplification from 20 mvdc to 5 vdc for 32 low-level analog channels
SCU	4	11.7	4	• MIU submodules are fabricated with beam lead devices mounted on ceramic substrates for maximum reliability
Wire Harnesses (All except power)	50	93	--	
Connectors	700	87.5	--	
Total (DMS)		392.3	333.6	
Guidance and Navigation Subsystem (G&N)				• DIGS IMU (space qualified); min DDT&E; 2 skewed packages (hexad)
DIGS IMU	2	100	240	• Strapdown startracker 8° x 8° FOV (space qualified on OAO)
Strapdown Startracker	2	32	12	• 10.0 nmi placement accuracy
Total (G&N)		132	252	• All-attitude capability
Communication Subsystem (Comm)				• Dual multiservice S-band system
Omni Antenna	4	10	--	• Compatible with STDN and AFSCF
Microwave Circuitry	1	24	20	• Redundant uplink and downlink
RF Multiplexer	1	4	--	• Omni-antennas for all-attitude RF coverage
Power Amplifier	2	16	74/144	• Microwave circuitry selects antennas singly or in pairs
STDN Transponder	1	26	32	• RF channel multiplexer acts as channel separator for USB and SGLS transmit/receive signals
SGLS Transponder	1	12	36	• Transponders provide tracking, ranging, transmission of PCM telemetry and reception of uplink data
Command Decoder	1	5	5	• Power amplifiers provide the necessary effective radiated power from tug to supply a margin above minimum required performance at the receiver
PCM Encoder	1	3	4	
Tape Recorder	2	40	25	• Modulator/demodulator processor is used for signal switching phase modulation (subcarriers) and demodulation of command subcarrier
Com Sec Equipment	2	12	14	
Mod Demod Processor	1	14	13	• The command decoder detects, decodes, verifies, and distributes commands
Total (Comm)		166	293	• The PCM encoder combines the telemetry data into formats and clocks out the PCM data to be modulated on a subcarrier
Instrumentation Subsystem				
Transducers and Sensors		26	107	• Existing sensors satisfy all measurement requirements
Instrumentation Power Supplies	6	36	54	
Total (Instr)		62	161	
Electrical Power Subsystem				
Silver Zinc Primary Battery – 775 amp/hr	2	430	--	• AgZn batteries for primary and TVC power
Silver Zinc Primary Battery 20 amp/hr	1	20	--	• AgZn cells previously qualified – new case
Nickel Cadmium Secondary Battery 15 amp/hr	1	37	--	• NiCd battery for backup power
Total (EPS)		487		
Electrical Power Distribution Subsystem				
Power Distribution Unit	1	20	30	• Electro-mechanical contractors and remote control circuit breakers driven by solid state drivers
Wire Harnesses	10	29	35	• Redundant buses
Total (EPDS)		49	65	
Equipment Thermal Control				• Heat pipes have 1/2-in. square cross section with stainless steel wick and ammonia working fluid; 10-ft long sealed sections curved to fit vehicles
Thermal Panels	--	71	--	
Heat Pipes	--	26	--	• Splice mechanism provides thermal conductivity between 10 ft sealed heat pipe sections to form circumferential hoop beneath panels
Splice Mechanism	--	30	--	
Radiation Shroud	--	15	-	• Eight mounting panels 7 to 19 ft² with heat pipes thermally attached to rear surface. Low adsorptivity and high emissivity surfaces. Maximum dissipation 350 watts per panel
Miscellaneous	--	2	--	
Total (ETC)		144		• Radiation shrouds protects panel from direct solar radiation
Total Avionics Weight and Power		1432.3	1104.6	

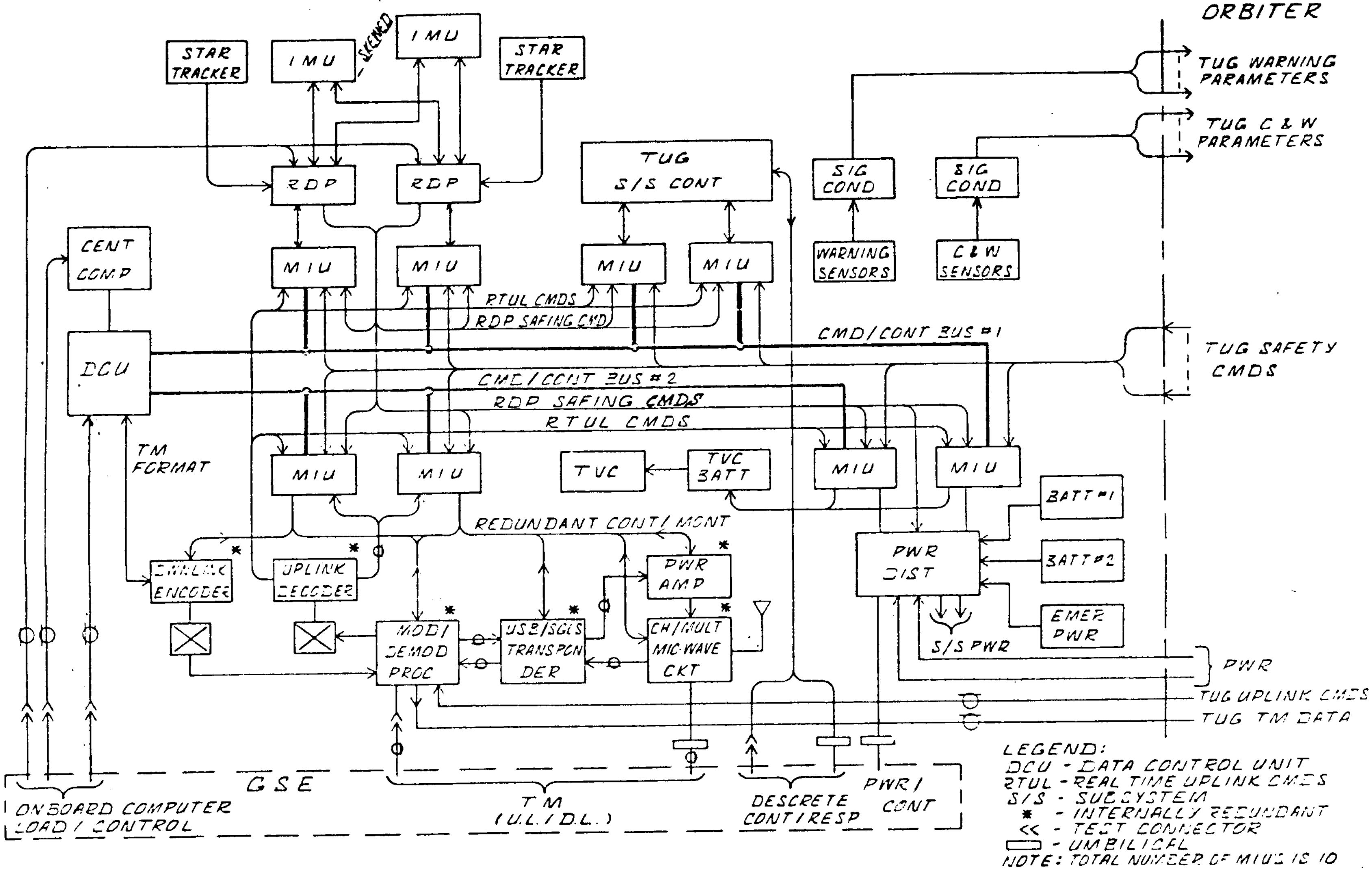


Figure 2-5. Avionics Block Diagram Program Option 1

computer failure. The onboard software is minimized in this option since the vehicle operates under the lowest level of autonomy (i.e., level IV).

The guidance, navigation, and control subsystem consists of two strapdown inertial measurement units (IMU's) from the existing Delta inertial guidance system (DIGS) and two existing strapdown star trackers. These units have been selected to minimize the DDT&E costs. The IMU's will be arranged in a hexagonal configuration to facilitate redundancy management. The star tracker will provide periodic attitude updates. The star-tracker data will be processed on the ground and attitude update data will be transmitted to the Tug via the uplink.

The communications subsystem consists of the following: S-band transponder/premodified processor, uplink encoder, power amplifier, a pulse code modulator (PCM) formatter, an omni-directional antenna, and associated microwave switching. The capability of supporting both Air Force and NASA missions is provided by a change of components between missions. The communications subsystem consists primarily of existing equipment. Redundancy for the subsystem is achieved in most cases internally to the line-replacement units (LRU's). Payload interface capability is not required nor provided.

The power subsystem utilizes two silver-zinc primary batteries to provide avionics power. One silver-zinc battery is used to power the thrust vector control subsystem, with a nickel-cadmium battery used for backup avionics power in case of emergency. The primary batteries will be activated on orbit under control of the Shuttle. The backup power source will provide the power for safing the vehicle for a limited time ($\simeq$30 min). The total power given in Table 2-2 represents peak power for this option.

Thermal control for the avionics modules in the front of the vehicle is provided by lightweight radiation shields, which are installed over the panels in the forward skirt to provide protection from radiation when the vehicle orientation is toward the sun. Heaters are provided for orientation away from the sun. Heat pipes are used to pump heat from the hot side to the cold side when the vehicle is oriented at right angles to the sun. Heat pipes are also used to control the temperature of the mid-skirt electronics to stabilize the temperature of the electronic modules. The final design goal is to avoid having operational constraints on vehicle orientation imposed by the onboard electronics thermal control requirements.

Avionics analysis and studies are discussed in detail in Volume 5.

2.5 PROPULSION SUBSYSTEM SUMMARY (WBS 320-03-04)

The propulsion subsystem is design to the program requirements established for Option 1. The driving requirements for subsystem selection were minimum DDT&E and sufficient performance for the Tug to deploy a minimum payload of 3,500 lb to geosynchronous orbit. The selected propulsion assemblies are defined to emphasize these requirements and are summarized herein: the assemblies are the main engine, main engine support, attitude control propulsion system (ACPS) engine, and ACPS engine support.

2.5.1 Main Engine

The Category I RL10 engine was selected for the Option 1 Tug; its principal performance and geometric characteristics are:

Vacuum thrust (lb)	15,000
Engine mixture ratio	5.5
Vacuum I_{sp} (sec)	441.8
Expansion ratio	57 ~~54~~:1
Dry weight (lb)	293
Length (in.)	70.1
Diameter (in.)	39.5

The main propulsion system schematic is shown in Figure 2-6. The schematic shows all of the Tug main propulsion subassemblies, plus the main propellant tank insulation vent and purge. In addition, the schematic shows the fluid lines and hardware located in the Orbiter payload bay and Orbiter aft section which are required to support the Tug.

The Tug features a Category I RL10 main engine with GH_2 bleed for LH_2 tank pressurization, and an ambient helium assembly for repressurization and LO_2 expulsion. Also shown are the vent, main engine feed, fill and drain, LO_2 suborbital dump, and LH_2 horizontal drain subassemblies.

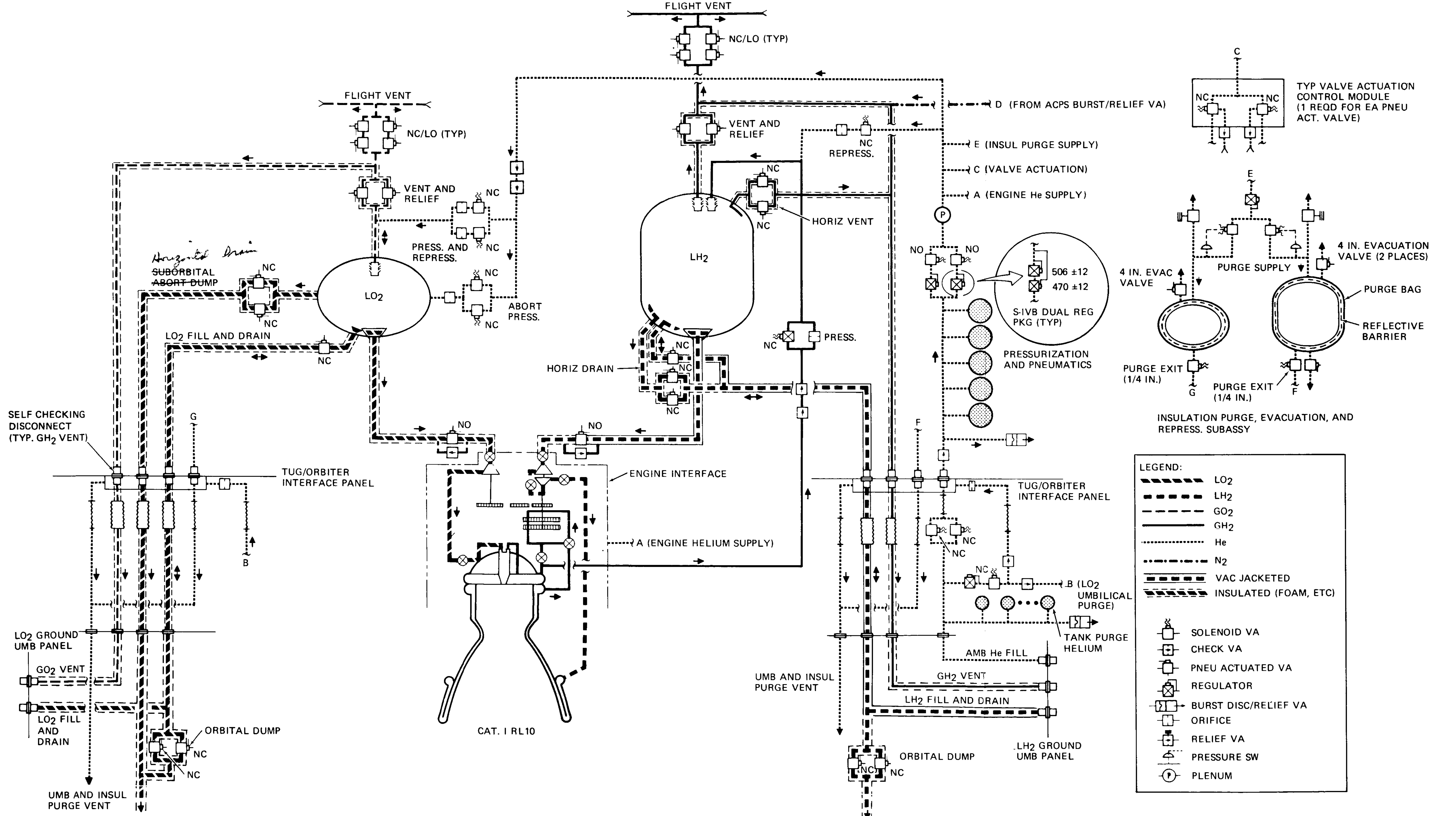


Figure 2-6. Main Propulsion Schematic Option 1

The Orbiter side of the interface shows the LH_2 tank purge helium provisions and the ambient helium fill, fill and drain, main tank vent, orbital dump, and LO_2 suborbital abort dump line provisions.

2.5.2 Main Engine Support

The main engine support assembly is basically composed of hardware subassemblies, e.g., feed, or fill and drain. However, nonhardware selections are also included in this category; i.e., main tank propellant orientation and feedline and engine thermal conditioning. The main engine support selections are shown in Table 2-3.

2.5.3 Attitude Control Propulsion System

The ACPS system is a simple, monopropellant blowdown design. Propellant (N_2H_4) is stored under pressure in three spherical tanks. The tanks are half-loaded by a vacuum loading scheme with propellant. The outer half, separated from the propellant by an elastic diaphragm, contains nitrogen gas under pressure.

Propellant is directed to each of four thruster pods, with each pod containing four thrusters, via a propellant feed system. The thruster arrangement affords six-degrees-of-freedom for attitude control. A network of isolation valves in the propellant feed system provides fail-operation/fail-safe performance.

The major performance characteristics of the system are presented in Table 2-4, while a description and source identification of the major components are given in Table 2-5.

The ACPS schematic with instrumentation is presented in Figure 2-7, which shows the propellant tank manifolds, feed system to the ACPS thrusters, and the APS thruster and thruster module isolation valving required to achieve fail-operation/fail-safe reliability. The figure also shows provisions for filling and draining propellants and pressurization with nitrogen. A detailed discussion of system operation is given in Volume 5, Section 2.4.4.3. Propulsion analysis and studies are also discussed in detail in Volume 5.

Table 2-3

MAIN ENGINE SUPPORT SUMMARY OPTION 1

Main Engine TVC:	Apollo service propulsion system electromechanical actuators.
Main Engine Feed:	LH_2 - 2.5-in. vacuum jacketed ducting tank to Parker 2-in. prevalve. Two-inch insulated S-IV design, ducting prevalve to engine. LO_2 - 2.0-in. insulated ducting and Parker 2-in. prevalve S-IV design, ducting prevalve to engine interface.
Vent (typ for LH_2 and LO_2):	Six-valve configuration - two Calmec vent-and-relief valves and four Calmec flight-vent isolation valves. Vent ducting through Tug-Orbiter interface, 2.0 in. Flight vent, 1 in.
Fill and Drain:	LH_2 - 2.0 in. vacuum jacketed ducting and Parker 2-in. valve. LO_2 - 2.0 in. insulated ducting and Parker 2-in. valve.
Pneumatics:	See pressurization.
Propellant Utilization:	Closed loop with capacitance probes.
Pressurization:	S-IVB derivative ambient He for repressurization of LH_2 and LO_2 and expulsion of LO_2. Engine GH_2 bleed for LH_2 expulsion.
Propellant Orientation:	ACPS thrusting using two aft-firing thrusters. Variable time depending on quantity of LH_2 in tank.
Engine and Feedline Conditioning:	Trickle-bleed propellants through engine and feedline. Propellants vented overboard.
LO_2 Abort Dump:	3.0-in. insulated ducting and parallel Fairchild butterfly valves.

Table 2-4

ACPS PERFORMANCE SUMMARY

Maximum Total Impulse Capacity	65,000 lbf/sec
Maximum Total Impulse Required	50,700 lbf/sec
System Loaded Weight at Maximum Total Impulse Capacity	440 lbm
System Loaded Weight at Maximum Total Impulse Required	380 lbm
Thrust Level of Thrusters	29.8 lbf blowdown to 17 lbf
Degrees-of-Freedom of Attitude Control	6
Fail-Operational/Fail-Safe ACPS	Yes
Thruster Arrangement	4 Pods of 4 each
Total Number of Thrusters	16
Number of Propellant Tanks	3

2.6 SHUTTLE INTERFACE (WBS 320-03-05)

The Shuttle Orbiter-Tug interface is composed of extensions of major Tug subsystems to the Orbiter as necessary for performing the major preflight, flight, and postflight operations. These operations are:

A. Preflight ground testing and checkout
B. Launch phase monitoring
C. Prerelease checkout
D. Activation of subsystems
E. Deployment of the Tug/payload
F. Monitoring in Orbiter proximity
G. Monitoring during Tug mission operation
H. Command/control in Orbiter proximity
I. Subsystem deactivation
J. Retrieval of the Tug/payload
K. Stowage of the Tug/payload
L. Passivation and safing of Tug/payload
M. Return flight monitoring
N. Safety provisions
O. Ground support interfacing.

Table 2-5

ACPS MAJOR COMPONENT DESCRIPTION

Thrusters:	
Number required	16
Model No.	MR-3C
Manufacturer	Rocket Research
Previous programs	Transtage
Propellant Tanks:	
Number required	3
Previous program	P-95
Diaphragm material	AFE 332
Size	22 in. dia sphere
Volume (each)	5,600 cu in.
Operating pressure	350 psia
Burst pressure	700 psig
Empty weight (each)	14.35 lbm

The Shuttle-Tug interface represents the provisions for mating two major systems, each of which is capable of independent operation when parted in space. While mated, the Tug is dependent to a degree on the support capability of the Orbiter and of the ground through the Orbiter. Although the vehicle is passive during most of the launch and landing periods, the Orbiter crew maintains continuous safety and monitors subsystem status.

The Shuttle conducts many missions which do not include the Tug, however, and it is essential that the Tug interfaces produce minimum effects in design and operations of the Orbiter. To minimize these impacts, the Tug ancillary hardware is designed for easy installation and removal. The cabin provisions consist of a dedicated portion of the mission specialist station and multiplexed interfaces with the Shuttle data-management, computation, and display

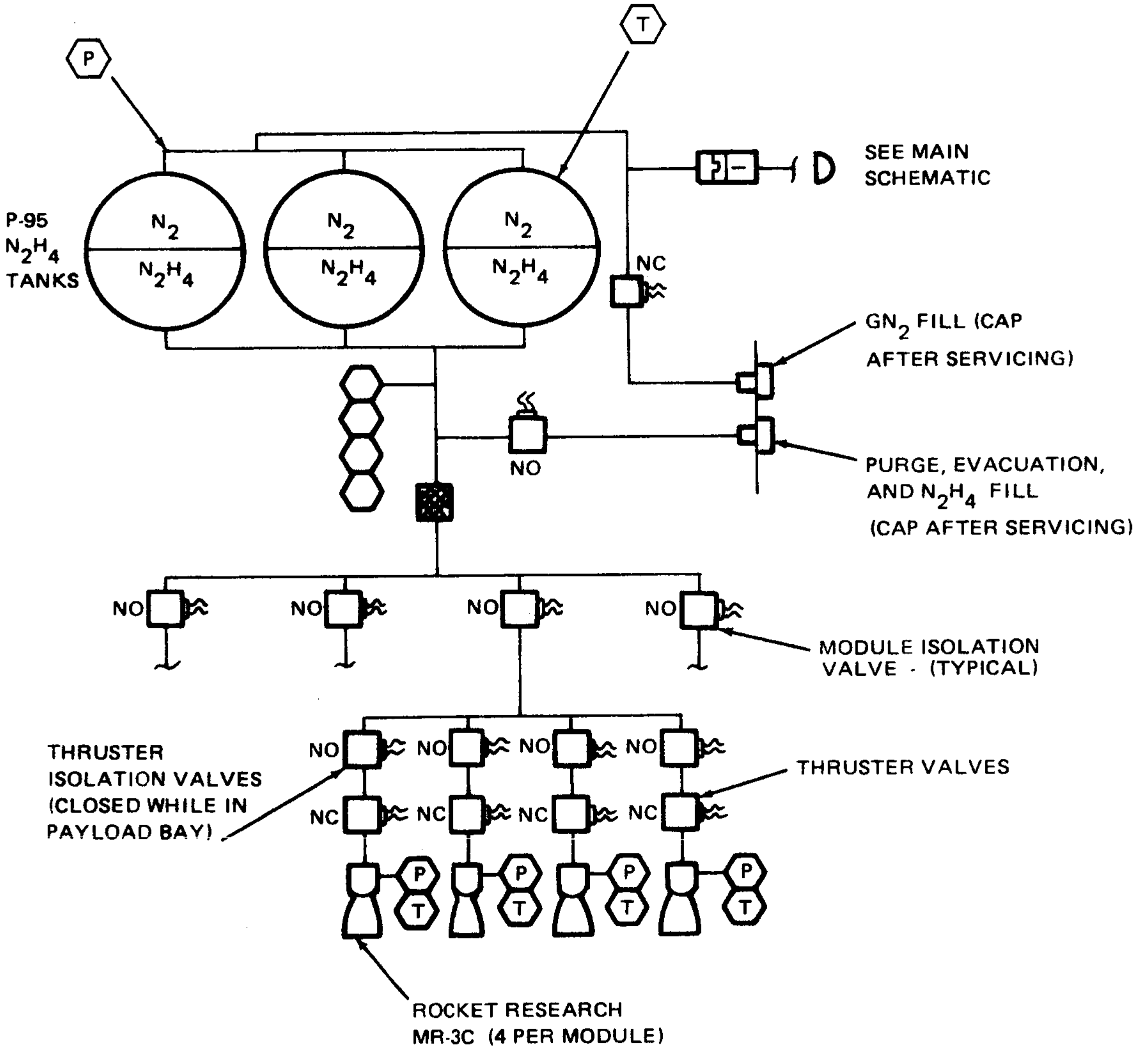


Figure 2-7. ACPS Schematic

equipment. This allows accessing and display of Tug subsystem status for monitoring, diagnosis and, through the Tug-unique dedicated panel section, sufficient control to take corrective action.

The principal functions and hardware groups are listed below and are shown in Figure 2-8.

FUNCTIONS AND SERVICES

Operations (listed above and discussed in Volume 6).
Safety (discussed in Volume 7).
Structural/mechanical support (attachments, mountings, manipulation provisions)
Fluid/propulsion support (fill/drain/vent/purge/abort provisions)
Thermal conditioning support (temperature control provisions)
Avionics support (electrical/electronics, checkout/monitor/control provisions, with data management, communications, electric power, guidance/navigation/control subsystems)
Payload support (checkout/monitoring, control, caution/warning, safing, electrical power circuits routed through the Tug)

HARDWARE GROUPS

Tug support structure (tilt table)
Tug support attachments (hard points, latches, locks, support frame adapters)
Remote manipulating system (RMS arm is part of Orbiter mechanisms, Tug-unique end effector with TV and lighting is charged to Tug support)
Fill/drain/vent/purge/abort line assemblies (include vacuum-jacketed low-temperature lines and purging provisions)
Fluid panels and retraction mechanisms (purging provisions, locks, actuators, drives, drive controls)
Electrical and electronics support (instrumentation, sensors, caution-and-warning circuits, electrical cables/connectors, interface units, junction boxes, test points, inhibit functions/circuits/buses, drive control electronics, TV/lighting)

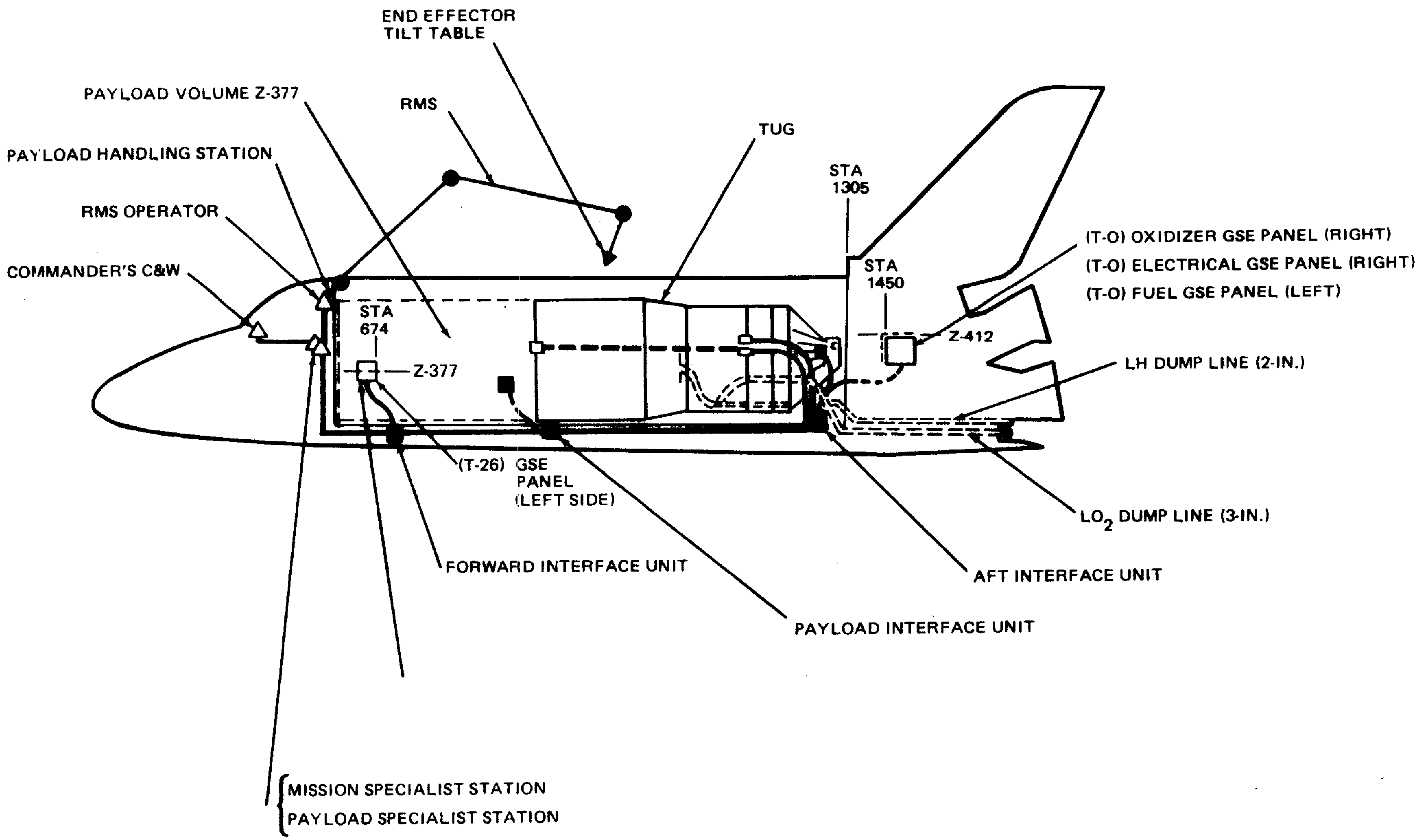


Figure 2-8. Shuttle-Tug Interfaces, Hardware Locations

The total weight of Shuttle interface hardware for Option 1 is 1,897 lb. This weight is detailed in the WBS weight statement in Volume 5. The hardware groups are described in Volume 5, Section 4.

2.7 PAYLOAD INTERFACE SUMMARY (WBS 320-03-01-06)

The payload interface structure, shown in Figure 2-1, consists of a square frame attached to an eight-member open truss. The truss was sized by a combination of maximum payload weight and Shuttle flight loads. The payload loads are transmitted through the truss into the Tug at the same forward frame hard point as the forward tank support. Structural latching between Tug and payload occurs at the corners of the square frame by means of spring-loaded, pneumatic-operated latches. The payload side of the interface consists of a ring whose diameter is equal to the diagonal distance across the square frame. A detailed description of this interface is given in Volume 5, Section 4.3.

There is a minimum electrical (avionics) interface between the payload and this Tug option. It consists of caution-and-warning signals required by the Shuttle; the wiring for these signals is routed through the Tug-Tug Orbiter interface.

Operationally, deployment is achieved while the Tug is limit-cycling for fine hold. The electrical interface is first mechanically disconnected and then the structural attachments are pneumatically unlatched at the four-corner latches. The Tug then backs away from the payload.

2.8 AUXILIARY (KICK) STAGE SUMMARY (WBS 320-04-01)

The use of a kick stage on four of the NASA planetary missions (19, 20, 21, and 23) allows these mission to be flown in a reusable mode with the Tug. These are the only missions where a kick stage was required.

A range of acceptable kick-stage sizes was established parametrically. A survey of existing solid-rocket motors was made in an attempt to identify existing stages which could be utilized for the Tug missions. Several constraints, such as stage length and thrust-to-weight, were used in making the final selection. The stage most nearly meeting the requirements was the second stage of the Polaris A3.

Design details of this stage are classified and may be found in a confidential document, Rocket Motors Manual (U) (Unit 411, Chemical Propulsion Information Agency, John Hopkins University).

In an attempt to minimize changes to a standard Tug-payload interface, the Tug payload-kick stage interface shown in Figure 2-9 was conceived. By replacing the standard Tug-payload interface truss with the one shown, the Tug-payload interface remains the same, except that the interface plane moves forward. The longer struts allow the kick stage to interface directly with the payload interface ring. There is no direct structual interface between the Tug and kick stage. The longer struts were designed by the combined payload kick stage loads. Electrical interface between Tug and kick stage is accommodated through the Tug-payload electrical interface panel. In essence, the kick stage appears as part of the payload to the Tug.

Operationally, the Tug separates from the payload-kick stage combination in the same manner as from a payload. The Tug provides the proper flight path angle prior to separation. After an appropriate separation distance is established, the kick stage is fired, completing the payload velocity requirement. The Tug is then free to return to the Shuttle.

Detailed analysis and trade studies may be found in Volumes 5 and 6.

2.9 MASS PROPERTIES SUMMARY

2.9.1 Weight

The weights are summarized in Table 2-6. The weight breakdown is structured after the WBS breakdown and contains a 10-percent contingency on the total dry weight. A new element has been added called margin, which has permitted the weight analysis to continue to be refined up to the last moment and not force an iteration of the programmatics. This margin, although small (2.5 percent), gives increased confidence that the stage mass friction can be achieved.

The weights presented herein are based upon the design defined in Volume 5, Book 1, Section 2. Additional weights and definition are given in Section 3 of Book 1, along with total vehicle mass properties.

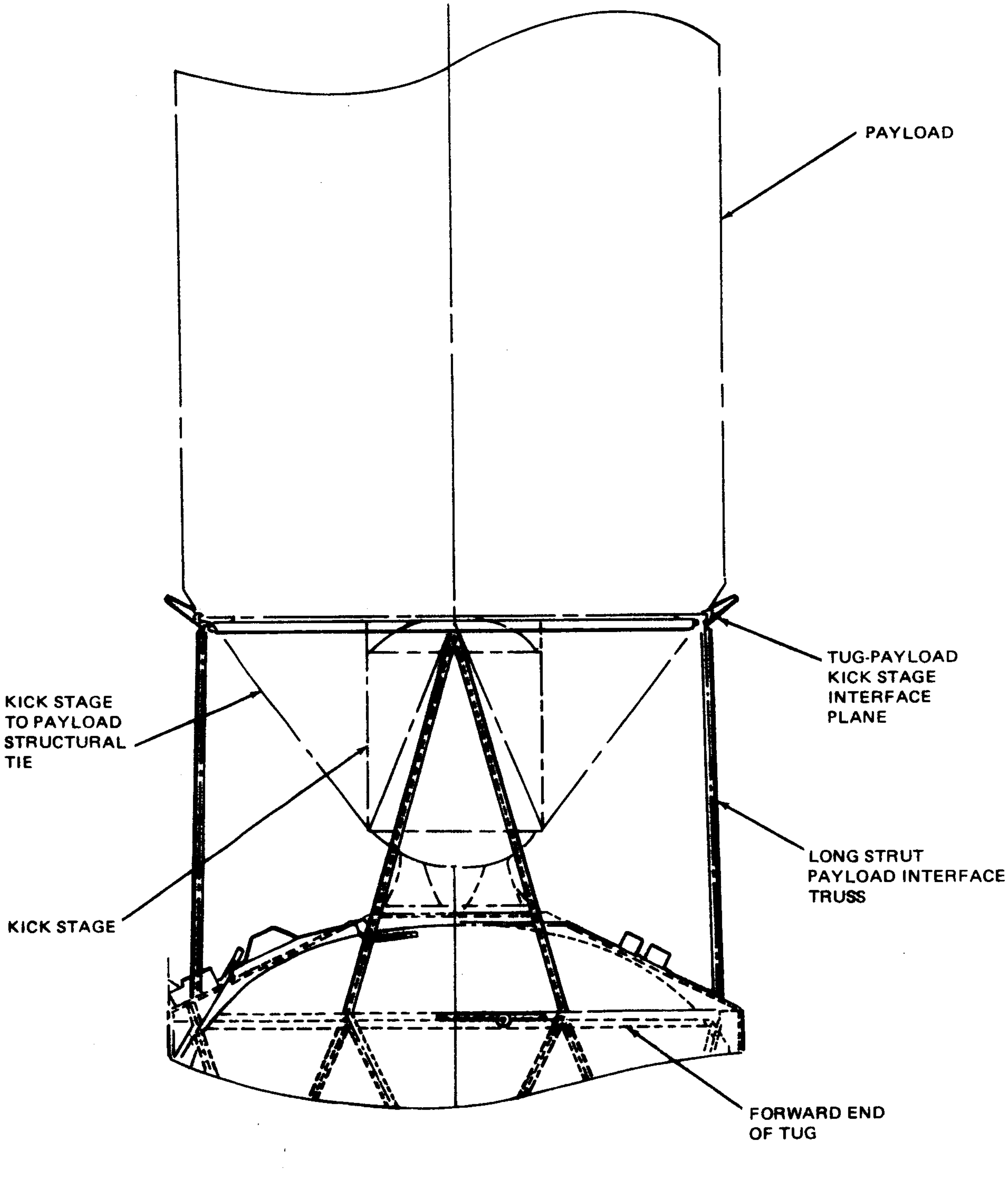


Figure 2-9. Tug-Payload - Kick Stage Interface

Table 2-6

WEIGHT STATEMENT FOR DEPLOYMENT MISSION, OPTION 1

	(lb)		
Structure	2,485		
Fuel tank and supports		869	
LO_2 tank and supports		264	
Body structure		1,069	
Shell			839
Supports			230
Thrust structure		106	
Meteoroid protection		65	
Payload interface		112	
Thermal Protection	196		
Fuel tank insulation		95	
LO_2 tank insulation		15	
Insulation purge		83	
Control system		3	
Avionics	1,446		
Data management		222	
Guidance and control		132	
Communications		152	
Instrumentation		215	
Electrical power source		487	
Power distribution and control		94	
Equipment thermal control		144	
Propulsion	1,599		
Main engine		293	
Main engine support		1,167	

Table 2-6

WEIGHT STATEMENT FOR DEPLOYMENT MISSION, OPTION 1 (Continued)

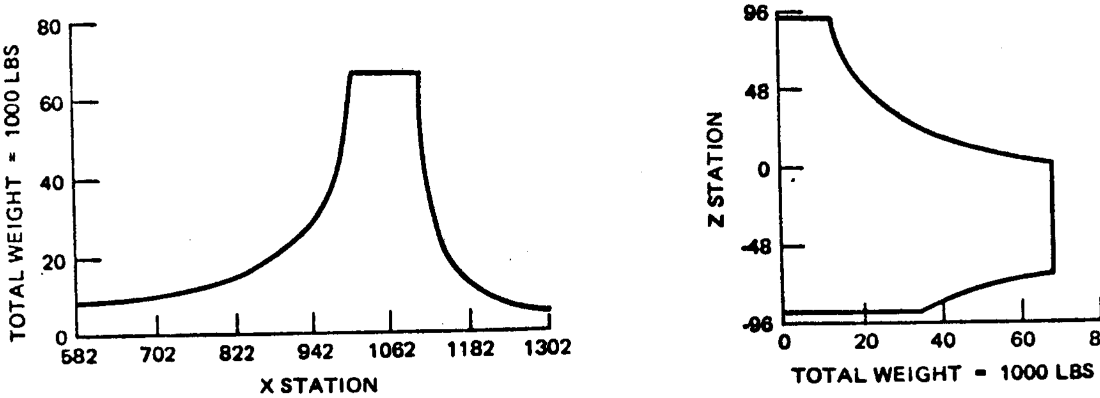
		(lb)
ACPS engine		66
ACPS engine support		73
Dry Weight	5,726	139
Contingency	573	
Margin	155	
Total Dry Weight	6,454	
Residuals		886
Burnout Weight	7,340	
Usable propellant		51,342
ACPS		236
Miscellaneous		416
In-flight losses		51,994
Payload		3,500
Orbiter Launch Weight	62,834	
Orbiter interface - cargo bay		1,627
Orbiter interface - remaining		270
Miscellaneous		269
Ground Launch Weight	65,000	

$$\text{Tug mass fraction} = \frac{\text{usable main propellant}}{\text{orbital launch weight - payload}} = 0.865$$

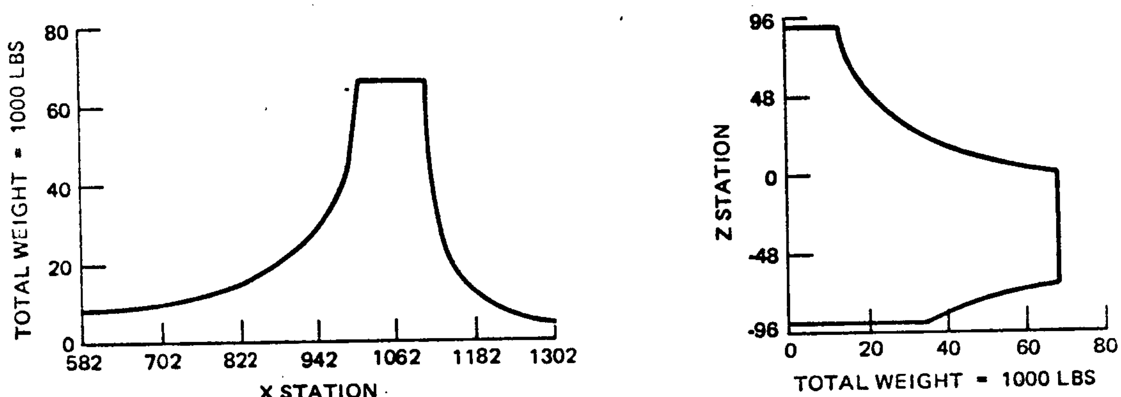
2.9.2 Center-of-Gravity

Figure 2-10 illustrates the three selected mission points for Orbiter center-of-gravity (cg) landing constraints. The only cg outside these limits is the fully loaded Tug with interface provisions. This constraint, applicable during abort for subsonic and hypersonic flight, is met by dumping approximately 20 percent of the LO_2 propellant during Shuttle main-engine burn with the remaining LO_2 dumped 30 sec after main engine cutoff (MECO). The abort summary and analysis are included in Volume 6, Sections 2.5 and 6.

FULL TUG INSIDE ORBITER



ABORT LANDING



NOTE:
X STATION SAME AS ORBITERS
Z CARGO BAY CENTER LINE REFERENCE IS 0.0, POSITIVE UP

EMPTY TUG INSIDE ORBITER

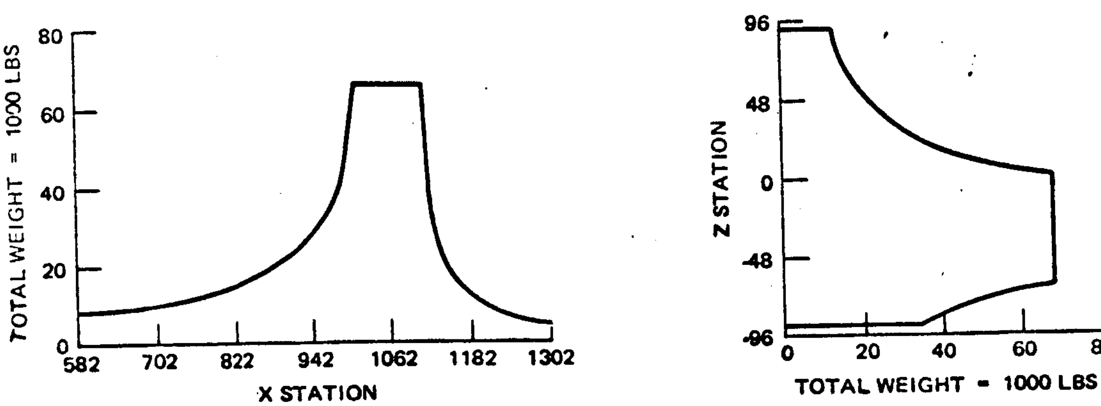


Figure 2-10. Orbiter Center-of-Gravity Limits, Option 1

2.10 RELIABILITY SUMMARY - OPTION 1

Two reliability design requirements were used to evolve the Tug configurations. The first was to ensure a minimum reliability of 0.97 for the overall Tug system; the second was to ensure all subsystems met the defined failure tolerance criteria; i.e., they were fail-safe as a minimum and fail-operational/fail-safe for critical functions. These two requirements are met by the Option 1 configuration for the single-stage Tug and are obtained for the augmented Tug, as shown in the following text. Table 2-7 summarizes the major subsystem reliabilities and the associated redundancy level necessary to meet the failure tolerance criteria and system reliability requirement.

Table 2-7

REDUNDANCY SUMMARY - OPTION 1

Subsystem/Reliability	Redundancy Level
Structures (0.999999)	None - Design per MSFC HDBK 505
Propulsion (0.991404)	
Main Engine	None - Fail-safe shutdown
Main Engine Support System	Component - Fail-safe shutdown
ACPS	Component - Fail-operational/fail-safe for critical functions
Thermal Control	None - Not critical per failure tolerance criteria
Avionics (0.991947)	Component - Except for computer which uses RDP for backup of stability function
Interface Systems (0.999871)	
Payload Separation	None - Fail-safe
Tug/OSS Separation	None - Fail-safe (Crew EVA action not included)
Total Reliability Single Stage (0.983221)	

A complete definition of the failure tolerance criteria and the compliance by subsystem is contained in Volume 5, Section 6. Essentially, the criteria are defined so that no single Tug failure may result in a hazard which jeopardizes the flight or ground crews.

The subsystem and system reliability prediction used standard methodology. The environmental adjustment factors (K-factors) and mission phase durations used are given in Table 2-8. Reliability calculation was based on:

$$R = 1 - \sum_{i=1}^{n} \lambda_i N_i T_i$$

where there are n items in the system, N of the ith item, and the failure rate (λ) is adjusted as shown in the detail assessment sheets of Volume 5, Section 6.

Table 2-8
TIME/K-FACTOR SUMMARY

Mission Phase	Duration (hr)	K-Factor
Launch and Boost	1/4	15
In Orbiter Bay (coast)	24	1
Tug Coast	Mission-dependent	1
Tug Engine Burn	1/2	7
Reentry	1/4	7
Nonoperating	Mission-dependent	1/25

Redundancy selection considered the system reliability requirement, weight penalty, and cost implications. Redundant items were added sequentially in order of the largest reliability improvement per pound of added weight to maintain low RDT&E costs and to achieve the most reliability improvement per added pound of weight. Considering the Burner II as representative of a kick stage, its presently predicted reliability is 0.982. Two of the possible alternates to meet the Tug reliability requirements of 0.97 with a kick-stage are:

A. Make one criteria for kick-stage selection that will have a reliability of 0.9847 for a 26-hour mission.

B. Increase the single-stage Tug reliability to 0.9878 for the same mission time.

Figure 2-11 shows that for a mission time of 26 hours, the Tug would have a reliability of 0.9850, hence requiring an increase in reliability of 0.0028. Referring to Table 2-9, it is shown that this would be exceeded by adding a redundant computer/DCU/SCU, and also increase the possible mission times to 140 hours, as indicated in the figure.

Redundancies in the auxiliary control propulsion system and avionics meet fail-operational/fail-safe standards for critical functions in these subsystems.

Table 2-9

OPTION 1: RELIABILITY/WEIGHT SUMMARY

36 HOUR MISSION; 1 PAYLOAD DEPLOYED; BASELINE R = 0.9339

No. Items in System	No. Redundant	Nomenclature	Total Δ Weight (lb)	Δ Increase in R per lb wt	Redundant System R
40	20	Power Distribution	20	0.0004	0.9419
6	3	Inertial Measurement Unit	50	0.0003	0.9587
2	1	ACPS Press Transducer	1	0.0003	0.9590
4	2	ACPS Temp Transducer	1	0.0002	0.9592
2	1	Remote Data Processor	11	0.0002	0.9617
2	1	Star Sensor	16	0.00008	0.9629
10	5	Module Int Unit	135	0.00007	0.9727
2	1	Tape Recorder	20	0.00006	0.9741
2	1	Orbiter Elect Interface	20	0.00006	0.9753
12	6	Comm Comps	45	0.00005	0.9777
2	1	Inst and Software	100	0.00005	0.9827
2	1	Comp/DCU and SCU	26	0.0003	0.9897

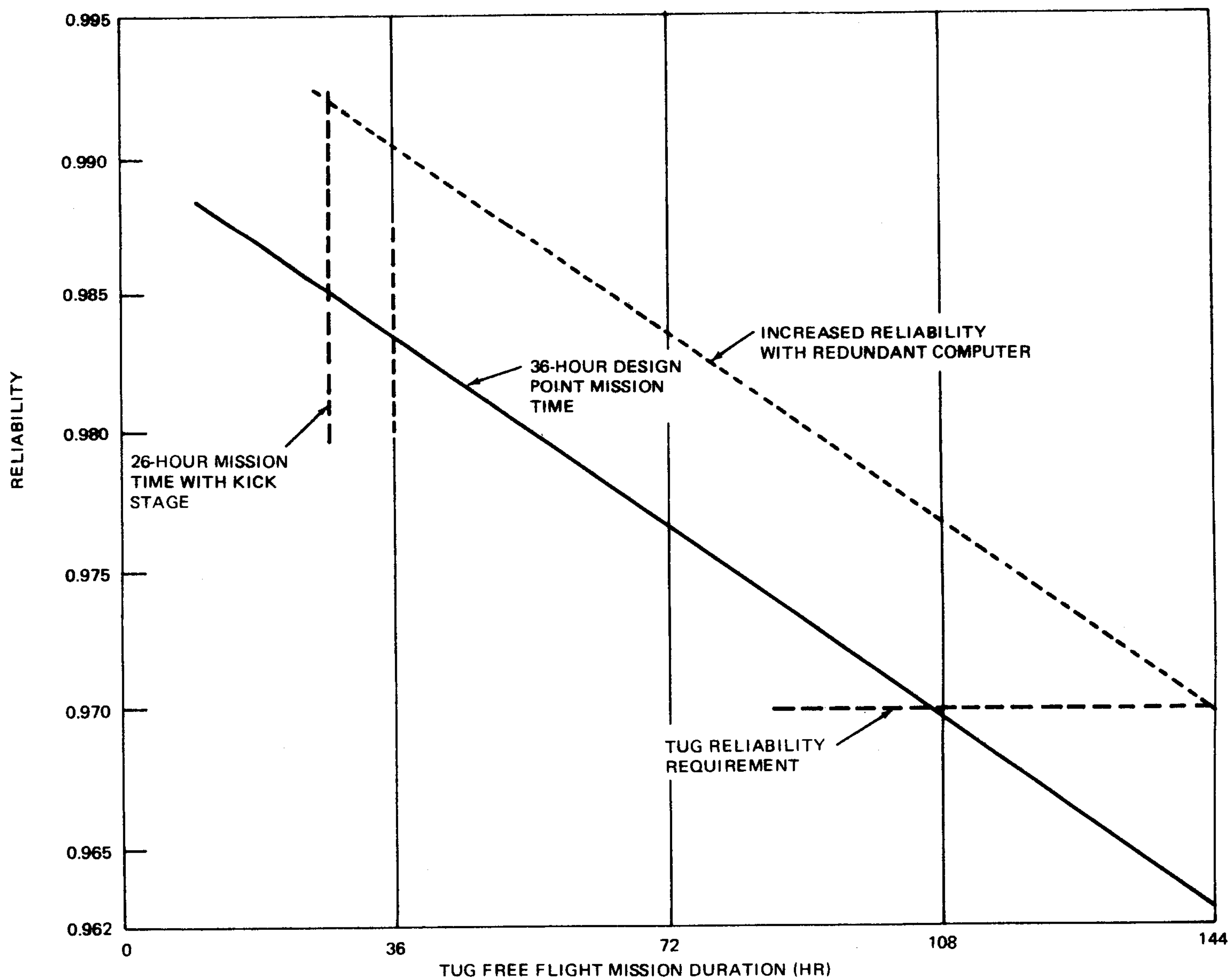


Figure 2-11. Reliability vs Mission Time (Option 1)

2.11 SYSTEM SAFETY

This Option 1 Tug, when designed, produced, and operated under the constraints of its criteria and requirements, will from a safety standpoint provide NASA with a vehicle well within an acceptable risk level for the Space Shuttle program. The following features should be incorporated.

2.11.1 Design

A. Burst disks and relief valves in the ACPS pneumatic supply system, ambient helium system, and the tank purge system. These systems will vent to the Tug overboard vent system.

B. Relief valves on the insulation purge bags.

C. Separate shut-off valves for the GH_e supply to the purge bags to preclude cross-flow of leaked propellants through the system.

D. A single-point failure of thruster chamber valve identified either by leakage or inadvertent operation. Valve design selection changed to provide two series valves, one normally closed and the other capable of latching in either the open or closed position.

E. Identified system inhibit and override functions.

F. Container for each battery to retain leaked or spilled electrolyte.

2.11.2 Production

A. Leak-rate levels of GH_e for H_2 system tests.

B. Preliminary analyses of refurbishment concepts to ensure identification of hazardous functions and reduce exposure to the hazards; i.e., safing of pressurized systems prior to disassembly, monitoring for toxic vapors, testing pressurized systems at levels acceptable for personnel exposure.

C. Preliminary analyses of the proposed materials and the fabrication methods show no new hazards.

2.11.3 Operations

A. Preliminary analyses of operational concepts to ensure identification of hazardous operations and sequencing those operations to reduce exposure to hazards; e.g., pressurization of GH_e pressure vessels with a 2-to-1 design ratio to a level not to exceed 4-to-1 when operational personnel are exposed, restraints in storable propellant loading and detanking, etc.

B. Items for crew warning-and-caution monitoring, hazard potentials at the tilt table interface, and at the Tug and Orbiter hard points.

C. The quantity of GH_2 to be dumped below 110,000 ft on reentry.

D. Toxicity levels for hydrazine and requirements for monitoring after the nonpropellant system is filled.

E. Results of analysis hazards related to abort and postlanding recovery.

F. Calculations to determine impact of fluids on the orbiter bay. These calculations are shown in Section 7.

2.11.4 Residual Hazards and Rationale for Acceptance

The residual hazards identified to date are corrosion, fire, explosion, pressure, and toxicity. The materials or situations which fit into any of these categories have been identified and the rationale for acceptance analyzed for each of the cases are presented in Table 2-10.

The analysis and rationale for acceptance of each of these hazards are discussed in detail in Volume 7.

Table 2-10

RESIDUAL HAZARDS

Source	Location
Corrosion	
Hydrazine	ACPS
Potassium hydroxide	Batteries
Fire	
Hydrogen	LH_2 tank and batteries
Hydrazine	ACPS
Thermal insulation	Encapsulates tanks
Wiring insulation	General
Bonding resins	General
Explosion	
Hydrogen	LH_2 tank and batteries
Hydrazine	ACPS
Pressure	
H_2 O_2 GH_e GN_2	Propellant tanks, pressurization and pneumatics purge system, and ACPS
Toxicity	
GN_2	Pressurant
GH_2	Propellant
GH_e	Purge
KOH	Batteries
Hydrazine	ACPS

Section 3

PERFORMANCE AND CAPABILITIES

3.1 PERFORMANCE

3.1.1 Mission Performance

The performance capability was computed for each mission in the mission model and for each mission mode — deploy, retrieve, round trip, and expendable. Table 3-1 summarizes the general mission descriptions. The performance results are given in Table 3-2. The derivation and application of these data are considered in Volume 4, Section 1.

3.1.2 Performance Envelope

The parameteric performance capabilities (payload vs velocity curves) are presented in Figures 3-1 through 3-3 for 28.5-deg, 55-deg, and 90-deg inclinations. Additional information on the inputs and applications of these data is given in Volume 4, Section 1. The numbered diamonds on the figures indicate the performance requirements for each mission.

3.2 MISSION CAPTURE

Missions for Option 1 commence from ETR in 1980 and from WTR in 1983. The total number of payloads scheduled for deployment by this option is 360, of which four are sortie missions requiring return to the Shuttle. Some missions carry multiple payloads, and 229 total missions will be made. The configuration is potentially capable of accomplishing all of the missions identified. The availability of the Shuttle for Tug missions in 1980 limits the Tug flights to three. This results in a lack of accomplishment of 20 of the deployment missions in that year.

The flight modes utilized by this Option include the following:

A. Basic Tug - Reusable

B. Basic Tug - Expendable

C. Basic Tug plus Polaris class auxiliary stage (kick stage)

D. Basic Tug - Dedicated mode.

Table 3-1

MISSION DESCRIPTIONS

Mission No.	$H_a \times H_p$ (nmi)	Inclination (deg)	Remarks
1-8	19,323	0	Synchronous orbit: single-burn transfer orbit injection
1-8A	19,323	0	Synchronous orbit: two-burn transfer injection
1-8B	19,323	0	Synchronous orbit: two-turn transfer injection with 600 fps for multiple payload deployments
9	1 AU	Eclip	
10	6,900	55	
10A	6,900	55	Alternate: Shuttle launched into 28.5 deg
11	16K x 30K	20	
12	180 x 1800	90	
13	1K x 20K	90	
13A	1K x 20K	90	ETR alternate: Shuttle launched into 28.5 deg
13B	1K x 20K	90	ETR alternate: Shuttle launched into 55 deg
14	300 x 3,000	90	
15	700	100	
16	500	99.2	
17-18	Interplanetary		ΔV - 13,000
19			16,500
20			23,000
21-22			24,000
23			18,400
24			22,000
D11	58,000	0,30,60	
D10	860 x 21K	63.4	Shuttle launch into 63.4 deg WTR
D10A	860 x 21K	63.4	ETR alternate: Shuttle launched into 55 deg
D5	750	99	
D3	13.6K x 25K	60	Shuttle launched into 60-deg WTR

Table 3-1

MISSION DESCRIPTIONS (Continued)

Mission No.	$H_a \times H_p$ (nmi)	Inclination (deg)	Remarks
D3A	13.6 x 25K	60	ETR alternate: Shuttle launched into 55 deg
D12	300	104	
D16	400	98.3	

The characteristics associated with the flight operations to accomplish the missions are presented below:

A. Multiple Deployment

B. NASA Mission Launches

  1. ETR 104
  2. WTR 16

C. DOD Mission Launches

  1. ETR 89
  2. WTR 16

D. Three reflights are required to accommodate mission losses due to failures.

The annual launch rate is summarized in the accompanying flight schedules (Tables 3-3 through 3-7) for NASA and the DOD and for the Eastern and the Western test ranges.

3.3 FLEET SIZE

The fleet size requirements for this program option result from two primary considerations: (1) the number of missions performed in the expendable mode, and (2) the number of Tugs required to perform in the last year of operations. The first parameter is a function of the capture analysis, while the second is a result of launch-to-launch cycle time.

A candidate usage and Tug introduction schedule are presented in the accompanying chart, Table 3-8.

Table 3-2

PERFORMANCE RESULTS

CØNFIGURATIØN ØPT 1 STAGE WT=7340.00 ISP=441.80 DELISP=4.00

MISSIØN	GRØSS-WT V-ØUT	PL-RØUND V-BACK	PL-DEPLØY	PL-RETRIEVE	PL-EXPEND
1-8	62665.00 13972.00	1310.76 13920.00	3521.35	2087.99	15900.11
1-8A	62665.00 13890.00	1361.27 13920.00	3657.04	2168.44	16035.79
1-8B	62665.00 14190.00	998.42 14220.00	2739.99	1570.82	15543.22
9	62665.00 14160.00	939.44 14350.00	2602.03	1470.28	15592.01
10	50665.00 9700.00	5440.99 9700.00	10833.03	10931.39	18106.98
10A	62665.00 12760.00	2897.37 12760.00	7168.42	4862.89	17988.35
11	62665.00 12450.00	3358.05 12450.00	8127.34	5722.47	18551.96
12	32665.00 2285.00	16274.57 2285.00	19140.84	108681.37	20433.55
13	32665.00 8400.00	2570.66 8400.00	4666.97	5723.02	10652.55
13A	62665.00 13460.00	1928.80 13460.00	5015.20	3134.18	16760.40
13B	50665.00 11200.00	2989.24 11200.00	6620.35	5450.08	15536.43
14	32665.00 3600.00	12252.56 3600.00	15820.59	54327.76	17958.04
15	26665.00 1700.00	13606.58 1700.00	15351.94	119681.69	16293.46
16	26665.00 1120.00	15404.58 1120.00	16679.45	201542.69	17286.90
17-8	62665.00 13140.00	2284.20 13250.00	5851.40	3746.85	17314.18
19	62665.00 16740.00	.00 17210.00	.00	.00	11753.93
20	62665.00 23550.00	.00 24500.00	.00	.00	4434.11

Table 3-2

PERFORMANCE RESULTS (Continued)

21-2	62665.00	.00	.00	.00	3588.35
	24600.00	25500.00			
23	62665.00	.00	.00	.00	9250.04
	18720.00	19550.00			
24	62665.00	.00	.00	.00	5345.34
	22500.00	23500.00			
D11	62665.00	1330.44	3576.74	2118.43	15969.50
	13930.00	13930.00			
D10	48665.00	7216.95	13195.53	15928.77	19276.04
	8500.00	8500.00			
D10A	50665.00	5260.80	10548.90	10494.46	17926.97
	9800.00	9800.00			
D5	26665.00	13399.42	15193.52	113474.25	16176.30
	1770.00	1770.00			
D3	48665.00	1706.80	3958.64	3000.51	13642.44
	11850.00	11850.00			
D3A	50665.00	1985.46	4627.86	3477.30	14396.47
	11920.00	11920.00			
D12	26665.00	17497.61	18129.87	501743.19	18395.09
	500.00	500.00			
D16	26665.00	16293.48	17306.96	278240.25	17763.52
	850.00	850.00			

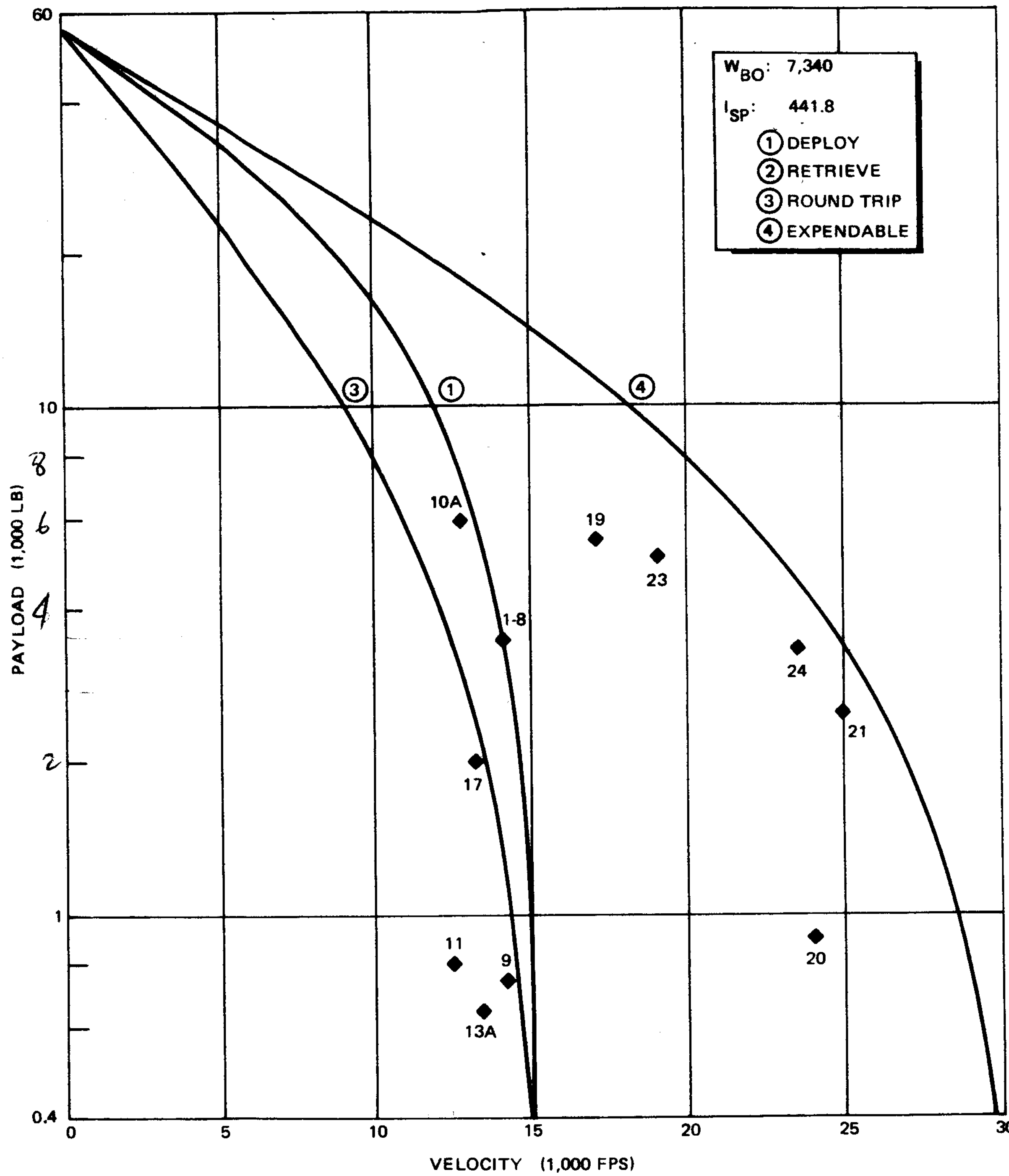


Figure 3-1. Performance Capability Configuration, Option 1 -- Inclination: 28.5 deg

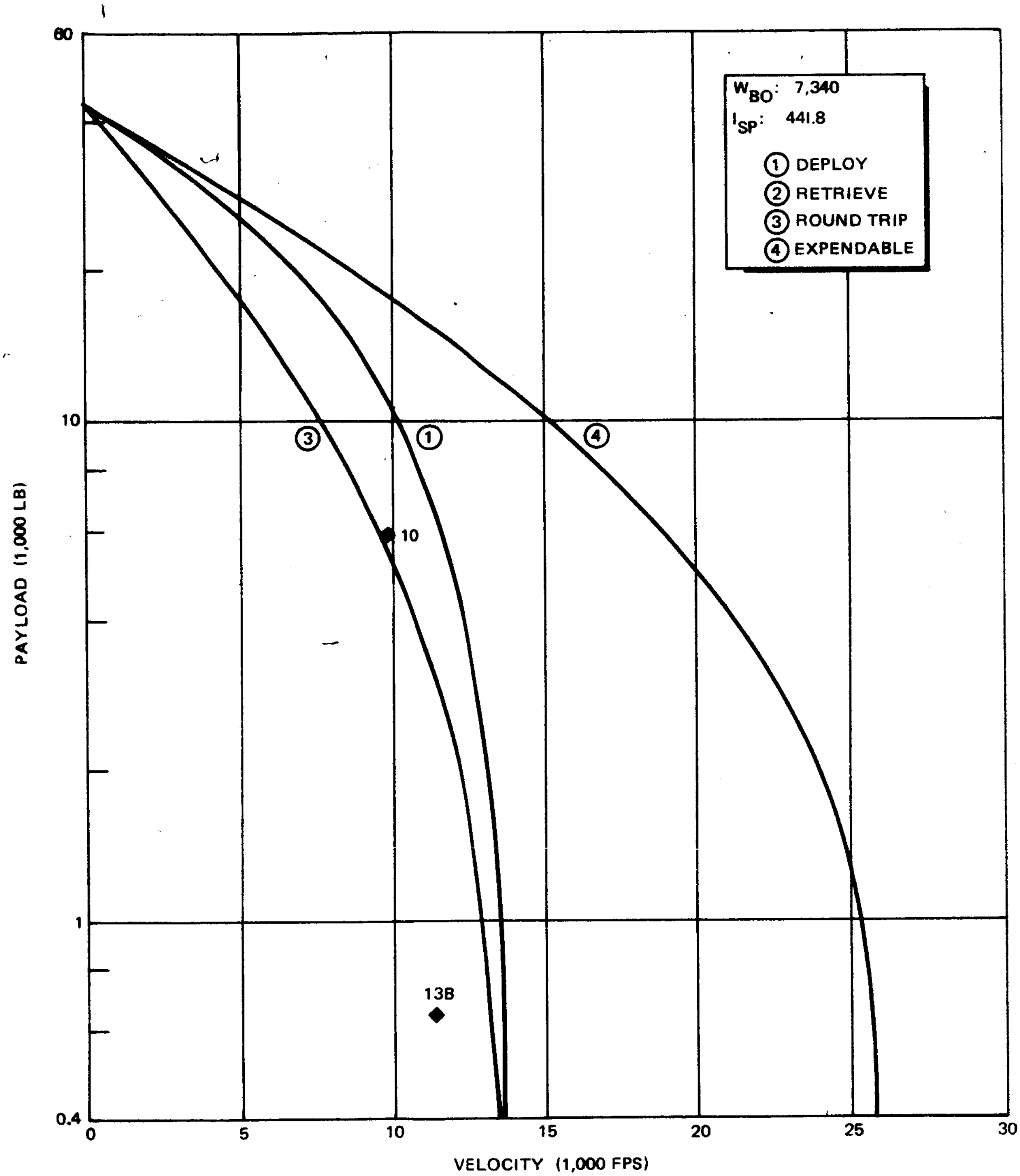


Figure 3-2. Performance Capability Configuration, Option 1 -- Inclination: 55 deg

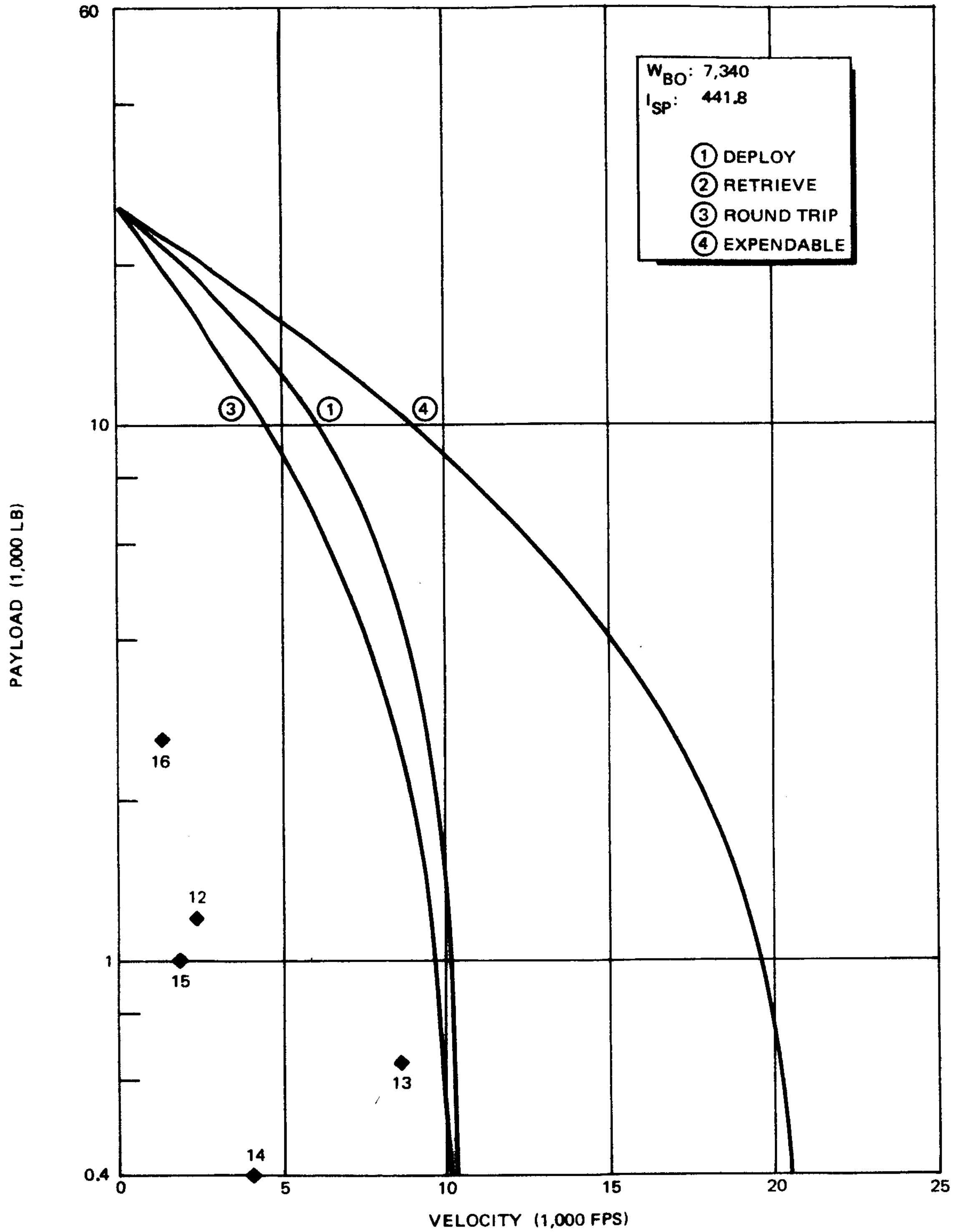


Figure 3-3. Performance Capability Configuration, Option 1 -- Inclination: 90 deg

Table 3-3

FLIGHT SCHEDULE

TUG CONCEPT: Option 1

LAUNCH SITE: ETR/WTR AGENCY: NASA/DOD

COMPANY: MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)**		3	14	16	30	(2) 26	22	(1) 21	(1) 28	20	(3) 28	(1) 20	(8) 228
Auxiliary Stage				(2)		(2)		(3)	(2)				(9)
Drop Tanks													0
(Other)	1*												1
Shuttle**	1*	3	14	16	30	26	22	21	28	20	28	20	229

( ) Denotes number expended.

Remarks: 20 payloads not accommodated due to Shuttle limit of three Tug flights in 1980

*Interface Verification Unit test flight

**Includes reflights due to Tug reliability losses.

Table 3-4

FLIGHT SCHEDULE

TUG CONCEPT: Option 1

LAUNCH SITE: ETR AGENCY: NASA

COMPANY: MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)		3	8	8	11	(2) 13	9	(1) 9	(1) 14	8	(3) 13	(1) 8	(8) 104
Auxiliary Stage				(2)		(2)		(3)	(2)				(9)
Drop Tanks													0
(Other)	1*												1
Shuttle	1*	3	8	8	11	13	9	9	14	8	13	8	105

( ) Denotes number expended.

Remarks: Nine NASA payloads not accommodated due to Shuttle limit of three Tug flights in 1980

*IVU test flight.

Table 3-5

FLIGHT SCHEDULE

TUG CONCEPT: Option 1

LAUNCH SITE: ETR AGENCY: DOD

COMPANY: MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)			6	8	11	11	8	8	10	10	7	10	89
Auxiliary Stage													0
Drop Tanks													0
(Other)													0
Shuttle			6	8	11	11	8	8	10	10	7	10	89

( ) Denotes number expended.

Remarks: 11 DOD payloads not accommodated due to Shuttle limit of three Tug flights in 1980.

Table 3-6

FLIGHT SCHEDULE

TUG CONCEPT: Option 1

LAUNCH SITE: WTR AGENCY: NASA

COMPANY: MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)					3	1	3	1	2	1	4	1	16
Auxiliary Stage													
Drop Tanks													
(Other)													
Shuttle					3	1	3	1	2	1	4	1	16

( ) Denotes number expended.

Table 3-7

FLIGHT SCHEDULE

TUG CONCEPT: Option 1

LAUNCH SITE: WTR AGENCY: DOD

COMPANY: MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)					4	1	2	2	2	1	3	1	16
Auxiliary Stage													
Drop Tanks													
(Other)													
Shuttle					4	1	2	2	2	1	3	1	16

( ) Denotes number expended.

Table 3-8

EQUAL USAGE SCHEDULE, OPTION 1

	80	81	82	83	84	85	86	87	88	89	90	Total
Number of Flights	3	14	16	29	26	22	20	28	20	27	20	225
Number of Expended Tugs					2		1	1		3	1	8
Tug Identification												
1	2	4	2	3	3							14
2	1	6	2	6	6							21
3		4	4	6	5	3	2					24
4			4	6	4	3	3	3				23
5			2	4	4	4	4	2	2	2		24
6			2	4	4	4	4	4	2	2		24
7						8	7	4	3	2		24
8								10	10	2	2	24
9								7	3	8	6	24
10										11	12	23
Reflights/ Losses				1			1			1		3

At the top of the chart, the number of flights per year is shown with the number of Tug expendable flights. The number of Tugs was established by first determining the number of Tugs necessary to accomplish the 1,990 requirements and working backward from that point. The maximum number of flights any Tug can perform in a year is established first by summing the Tug ground turnaround time and the mission time which results in the minimum mission turnaround time. In Option 1, the ground turnaround time is 26.7 days and the average mission time is 1.7 days. The mission turnaround time is thus 28.4 days. The maximum number of cycles (flights) in a year is then 12.

Using this number and assuming that the maximum number of flights that an expended Tug can make in the year it is expended is six (half the maximum turnaround in a year), the fleet of three is established for 1990. Working backward from there, it can be seen that in 1989, the three expendable requirements and those necessary in 1990 make up the inventory required. The resulting data show that to carry out the operations, a total of 10 Tugs are required during the program. Using the Government ground rules for reliability losses, three additional vehicles are required. Thus, the total fleet size necessary is 13, of which two are required in 1980.

Section 4
OPERATIONS

4.1 FLIGHT OPERATIONS

The work breakdown structure for the Tug Study divides the flight operations into four areas or blocks, namely: Mission Planning, Flight Control, Flight Evaluation, and Flight Support Software. The methodology for deriving the manpower requirements for each of these is presented in Volume 6.

Option 1 consists of a configuration with autonomy level IV and program duration (11 years); it does not have rendezvous, docking, nor spin-up capability and it is a direct development program. The mission duration is three days. The appropriate factors, numbers of flights, and mission times were inserted into a computer program and the resulting manloads were obtained. These are presented in Tables 4-1 and 4-2, and Figures 4-1 and 4-2.

Table 4-1

OPTION 1 COMPUTERIZED MANLOADS

OPTION = 1

TOTAL PROGRAM COSTS

NUMBER OF FLIGHTS =120,0

AUTONOMY LEVEL = 4,0

NASA MISSION

LAUNCH FROM WTR = 16,0

LAUNCH FROM ETR =104,0

FLIGHT OPERATIONS RECURRING COSTS (NASA ONLY)

		MANHOURS	COMPUTER HOURS	COSTS
MISSION PLANNING	=	247132,2	2262,3	5809093,2
FLIGHT CONTROL	=	921684,6	8591,2	21724139,2
FLIGHT EVALUATION	=	203983,2	2684,0	5107631,3
FLIGHT SOFTWARE	=	137280,0	1504,2	4008096,0
UNUSED MANHOURS	=	520155,4	0,0	10403107,5
TOTAL OPS, HOURS	=	1372800,0	15041,7	
TOTAL OPS, COSTS	=	30888000,0	5760959,7	36648959,7

OPERATIONS PER/FLT COSTS = 305408,0

FLIGHT OPERATIONS NON-RECURRING COSTS (TOTAL PROGRAM FOR BOTH DOD & NASA)

		MANHOURS	COMPUTER HOURS	COSTS
MISSION PLANNING	=	190320,0	891,0	4623453,0
FLIGHT CONTROL	=	31200,0	0,0	702000,0
FLIGHT EVALUATION	=	0,0	0,0	0,0
FLIGHT SOFTWARE	=	162750,6	2964,2	4797165,5
TOTAL DDT E HOURS	=	384270,6	3855,2	
TOTAL DDT E COSTS	=	8646089,4	1476529,1	10122618,5

Table 4-2

OPTION 1 COMPUTERIZED MANLOADS

OPTION = 1

TOTAL PROGRAM COSTS

NUMBER OF FLIGHTS =105,0

AUTONOMY LEVEL = 4,0

DOD MISSION

LAUNCH FROM WTR = 16,0

LAUNCH FROM ETR = 89,0

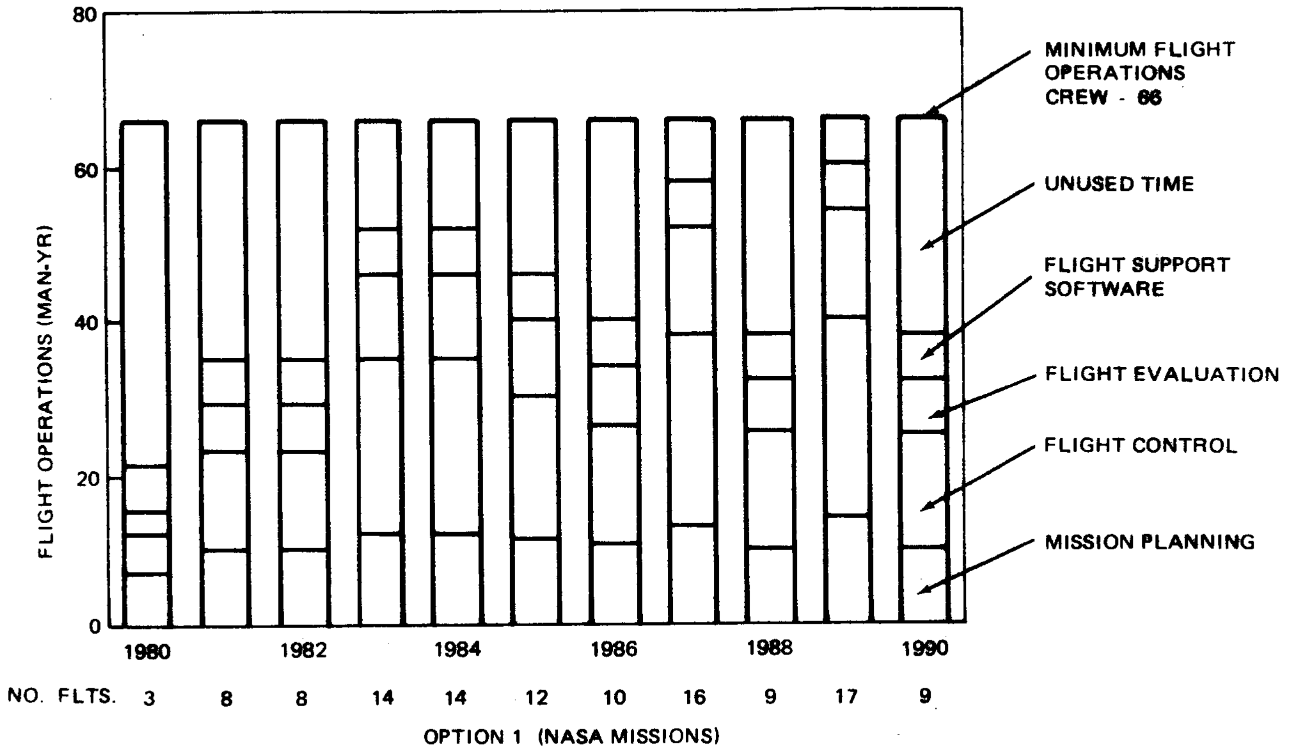
FLIGHT OPERATIONS RECURRING COSTS (DOD ONLY)

		MANHOURS	COMPUTER HOURS	COSTS
MISSION PLANNING	=	220743,0	2015,8	5186846,4
FLIGHT CONTROL	=	849562,2	7462,5	19848180,6
FLIGHT EVALUATION	=	177757,0	2338,9	4450961,2
FLIGHT SOFTWARE	=	124800,0	1313,0	3622887,6
UNUSED MANHOURS	=	500021,4	0,0	10000421,7
TOTAL OPS, HOURS	=	1248000,0	13130,2	
TOTAL OPS, COSTS	=	2880000,0	5028875,8	33108875,8

OPERATIONS PER/FLT COSTS = 318322,6

FLIGHT OPERATIONS NON-RECURRING COSTS (TOTAL PROGRAM FOR BOTH DOD & NASA)

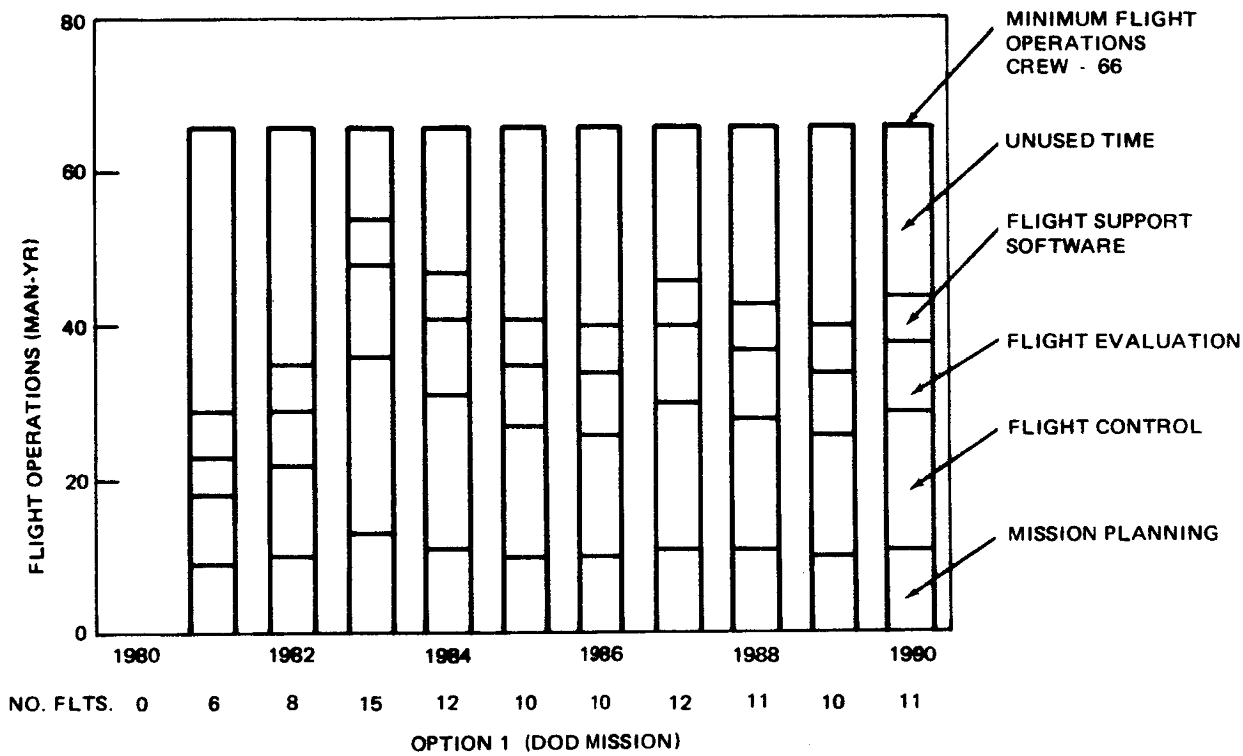
		MANHOURS	COMPUTER HOURS	COSTS
MISSION PLANNING	=	190320,0	891,0	4623453,0
FLIGHT CONTROL	=	31200,0	0,0	702000,0
FLIGHT EVALUATION	=	0,0	0,0	0,0
FLIGHT SOFTWARE	=	162750,6	2964,2	4797165,5
TOTAL DDT E HOURS	=	384270,6	3855,2	
TOTAL DDT E COSTS	=	8646089,4	1476529,1	10122618,5



TOTAL MAN-YEARS	=	726
MISSION PLANNING	=	119
FLIGHT CONTROL	=	193
FLIGHT EVALUATION	=	97
FLIGHT SUPPORT SOFTWARE	=	66
UNUSED TIME	=	251

TOTAL FLIGHTS	=	120
WTR FLIGHTS	=	16
ETR FLIGHTS	=	104

Figure 4-1. Flight Operations Manpower Required



TOTAL MAN-YEARS	=	660
MISSION PLANNING	=	106
FLIGHT CONTROL	=	168
FLIGHT EVALUATION	=	85
FLIGHT SUPPORT SOFTWARE	=	60
UNUSED TIME	=	241

TOTAL FLIGHTS	=	105
WTR FLIGHTS	=	16
ETR FLIGHTS	=	89

Figure 4-2. Flight Operations Manpower Required

4.2 GROUND AND LAUNCH OPERATIONS

Results of the ground and launch operations analysis include the detailed definition of all ground and launch operations activities, equipment, manpower, and schedules at both the Eastern Test Range (KSC) and Western Test Range (VAFB) which are required to support both NASA and DOD Tug missions.

The overall study/program objectives related to the ground and launch operations are:

- Low cost for development and operation.
- Reusable and capable of operating throughout the program duration with refurbishment/replacement of life-limited components as required.
- A minimum reliability goal for the Tug of 0.97 for all mission phases.
- Tug design for return to earth in the Shuttle and reuse; with minimized maintenance and ground turnaround costs.
- Reducing as much as possible the maintenance and inspection of systems, resulting in minimum subsystem replacements between flights.

Consideration of these objectives resulted in the identification of 11 major analyses which were evaluated to determine the required ground and launch operations resources. These analyses and the summary of results are shown below:

	Analysis	Result
1.	Ground operations costs	ETR $54.06 million; WTR $21.35 million
2.	Manning requirements	Peak Year Manning ETR 159; WTR 89
3.	Active Tug fleet size	ETR 3 Max 1 Min; WTR 1
4.	Total program fleet size	ETR 8; WTR 2
5.	Two year IOC delay	ETR 184 Man Year Reduction
6.	Operations restrained by shuttle	Landing-to-Landing +21 hours Liftoff - 144 hours to liftoff

7.	Ground turn around time	ETR 301 NASA; 309 DOD ETR 306 NASA; 306 DOD
8.	Task description development	55 Functional Task Defined
9.	Facility requirements description	Requires a new payload processing facility at ETR and WTR.
10.	GSE description	78 types of GSE required. See Table 4-3.
11.	Maintenance/refurbishment/checkout impact on turn around	maintenance/refurbishment/ checkout requires ≈70 hours

Additional manpower and cost data is shown in Figure 4-3.

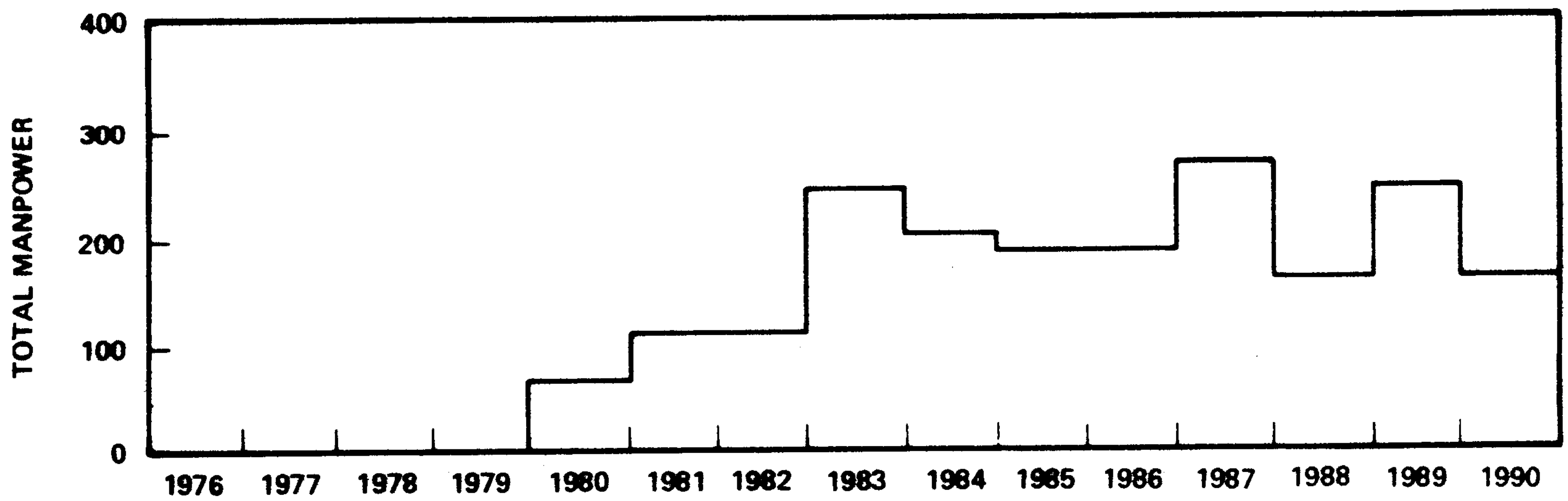
Appropriate data associated with each of these analyses and detail discussions are presented in Volume 6.

4.3 REFURBISHMENT SUMMARY

The MDAC Space Tug refurbishment concept minimizes these requirements while maintaining a satisfactory degree of launch on time probability, together with the required level of subsystem reliability to assure mission success. The concept is patterned after the commercial airlines "On Condition Maintenance" philosophy which monitors subsystem health and thus precludes unwarranted maintenance and refurbishment on subsystems, assemblies, and components which are functioning properly. Subsystem health is monitored by a combination of the following techniques.

- Operational instrumentation data consisting of subsystem performance measurements which are telemetered during flight via ground link.
- When the Tug is out of range of a ground tracking station, these data are recorded onboard for later transmission
- Post flight/receiving inspection.
- Automated subsystem checkout (ground) of those performance characteristics not readily adaptable to inflight monitoring
- Use of onboard checkout capability for fault detection and isolation.

The maintenance/refurbishment (M/R) technical approach/methodology is set sensitive to individual Tug configurations; however, the cost of an M/R cycle and depot maintenance will vary with different configurations. These variations have been expressed in the M/R inputs to the cost model for each



GROUND OPERATIONS	OPT 1
• TURNAROUND TIME	306 HRS
• AVERAGE MANPOWER	176
• TOTAL COST	$128 M
• LAUNCH SITE COSTS	$73.9 M
• MAINTENANCE COSTS	$23.8 M
• OPS COST PER FLIGHT	$0.435 M

Figure 4-3. Ground Operations Summary Option 1

configuration in terms of manhours/(M/R) cycle, equivalent units of production hardware for operational spares, and depot maintenance cost as a percentage of average subsystem hardware cost.

Maintainability Analyses

The maintainability analyses are provided in Volume 6. In addition, the analysis has produced predictions of risk of launch with an anomaly in the Tug and risk of pad loadout as a result of anomalies discovered subsequent to Tug/Shuttle mating.

The predictions are based upon a systematic analysis of the equipment operated (data management, fueling, communications, etc.) and length of operation according to the top-level functional flow diagram and system timelines. The total risk is apportioned to risk of pad loadout or to launch unreliability on the basis of individual subsystem verification capability incorporated in the design of the Tug and Tug/Shuttle combined integrated systems test. The results of the predictions are shown in a comparisons format in Figures 4-4 and 4-5.

4.4 GROUND SUPPORT EQUIPMENT (GSE)

Results of the GSE task include the detailed definition of the GSE, quantities, price, development schedule, and GSE at each location—factory, Eastern Test Range (KSC), and Western Test Range (VAFB)—to support both NASA and DOD Tug missions. It also includes a definition of Government Furnished Equipment (GFE) available from the Saturn and Delta program that is usable for Tug.

Option 1 features:

A. GSE is sized for fleet size of 13 vehicles for cradles, covers, and transporters.
B. Guidance and navigation checkout equipment GFE from Delta program.
C. Battery checkout GFE from Saturn program.
D. Factory GSE is shipped to VAFB to become launch checkout equipment for one pad. Feasible since schedule delivery of 13 vehicles allows enough time to accomplish this.

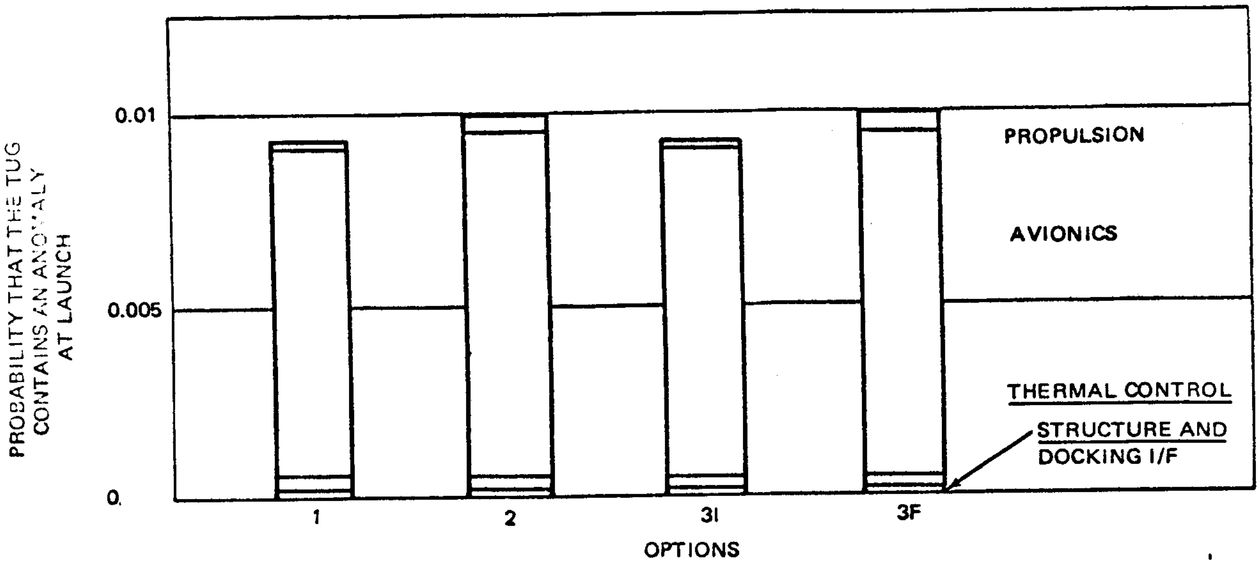


Figure 4-4. Comparisons of Tug Unreliability at Launch

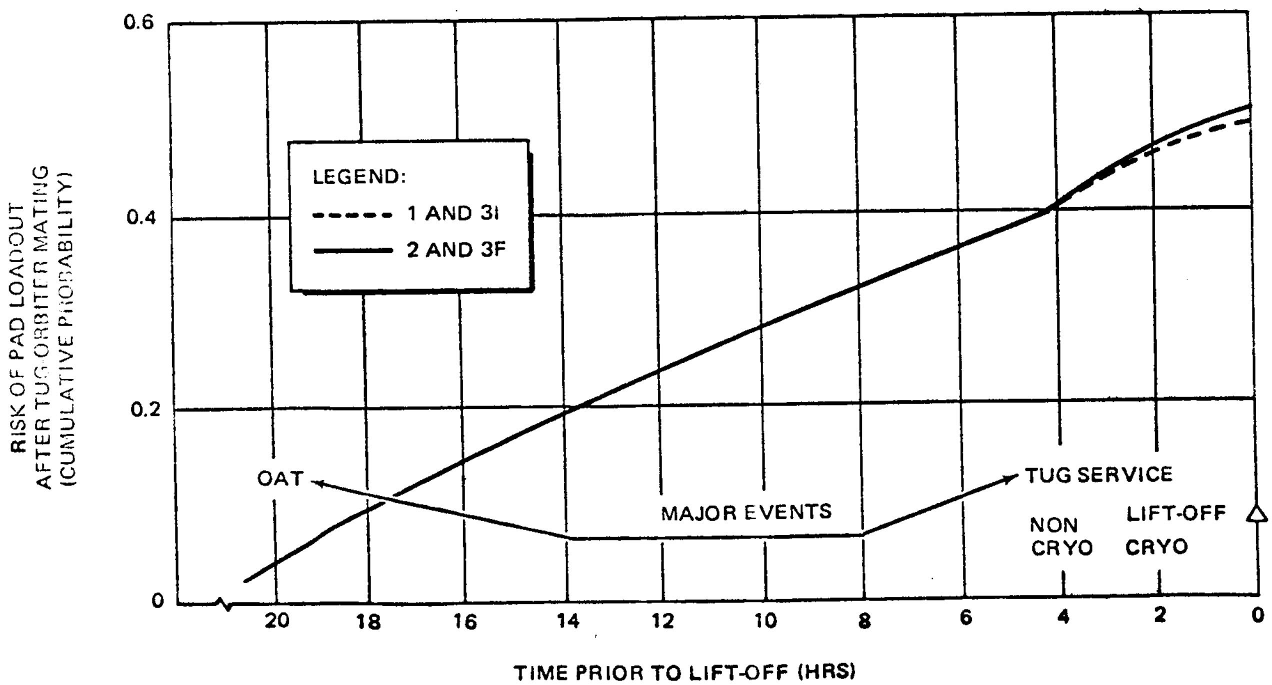


Figure 4-5. Risk of Tug Loadout Due to Prelaunch Anomaly

E. Provide only one pad of GSE at VAFB since launch rates are low from WTR and one set of hardware can support program launch rate from WTR.

F. Utilizes maximum GFE from Saturn program where possible to support KSC.

A summary of the GSE is shown in Table 4-3.

4.5 LOGISTICS SUMMARY

The MDAC Space Tug logistics concept incorporates the transportation and handling, training, inventory control, and warehousing functions and spares.

The primary mode of transportation between MDAC and KSC/WTR will be by "Guppy"-type aircraft when delivering new Tugs or when switching operational Tugs between KSC and WTR. Movement of Tug hardware (other than a complete Tug) will be accomplished via appropriate land and air modes as dictated by specific program requirements. The selection of preservation methods, packaging levels, and protective handling is based on analysis of natural and induced environments to which the hardware will be subjected during its life cycle.

Training

The training concept for the Tug Program is based on the premise that training will be required for all ground personnel (customer and contractor) and that personnel assigned to the Tug Program will already be skilled in their respective specialities; therefore, training requirements will be limited to the adaptation of their respective skills to Tug hardware and ground operations.

There will be no requirement for simulators and dedicated training equipment. Test and flight hardware, augmented by audio/visual aids, will be used. No special training facilities requirements are planned.

Inventory Control and Warehousing

The material control function includes the receiving, shipping, issue, repair, inventory control, and storage of spares, repair parts, and special test equipment (Contractor Furnished Equipment [CFE] and Government Furnished Equipment [GFE]) located at either the MDAC manufacturing facility or at the

Table 4-3 (Page 1 of 4)

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory Description	Total Units Required	Location Used			GFE Units Available
			Factory	ETR	WTR	
104	Air carry environmental kit -- VPG	1		1		
105	Air carry environmental kit -- VPG	1		1		1
106	Air carry roller transfer kit -- VPG	2		1	1	2
107	Air carry tie down kit -- VPG modified GFE	2		1	1	
108	Air carry tie down kit -- VPG	1		1		
110	Alignment kit	3		2	1	
111	APS breakout control box	3	1	1	1	
112	APS loading accessories kit	3	1	1	1	
113	APS servicer	2		1	1	
115	Battery handling kit	2		1	1	
117	Checkout accessories kit	9	1	4	4	
118	Checkout cable kit	11	1	5	5	
119	Communication system test set	3	1	1	1	
120	Component protective covers	6	1	3	2	
121	COMSEC equipment	3	1	1	1	3
122	Cover -- spacecraft	13		10	3	
123	Cover -- Tug	13		10	3	
124	Cradles	13	1	9	3	
125	Cryogenic propellant loading complexes	3		2	1	2
126	Cryogenic tank trucks	2		1	1	2
*127	Data management system T/S (DMST/S)	7	1	4	2	
128	Telemetry ground station	2		1	1	2
129	Digital events recorder	3	1	1	1	2
130	Engine actuator fixture	3	1	1	1	
131	Engine alignment kit	3	1	1	1	

*Factory units shipped to field centers for reuse.

Table 4-3 (Page 2 of 4)

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory	Total Units Required	Location Used			GFE Units Available
	Description		Factory	ETR	WTR	
132	Engine handling kit	3	1	1	1	3
133	Engine position calibration fixture	3	1	1	1	
134	Equipment van	6	1	3	2	5
135	FM transmitter component test set					
136	Frequency calibration unit rack assembly					
137	Fuel cell checkout kit					
139	Gas sampling equipment	6		3	3	
140	Handling equipment	10	2	4	4	
141	Horizon sensor tester					
142	Guidance and navigation test set	3	1	1	1	3
143	Guidance and navigation system checkout kit	3	1	1	1	3
144	Laser radar checkout and analysis kit					
145	Launch countdown console	3		2	1	2
147	LH_2-He heat exchanger	4	1	2	1	
*148	Signal conditioning unit	7	1	4	2	
149	Orbiter simulator	3	1	1	1	
150	Payload adapter handling kit	3		2	1	
151	PCM/FM telemetry component test set					
152	Personnel protection equipment	8		4	4	
153	Pneumatic console ACPS portable test set	3		1	1	1
*155	Power system T/S (PSTS)	7	1	4	2	
157	Printed circuit card component test set	1	1			
159	Propellant utilization component test set	3	1	1	1	
160	Propulsion component repair kit	3	1	1	1	
161	Propulsion pneumatic console (checkout)	5	1	2	2	3

*Factory units shipped to field centers for reuse.

Table 4-3 (Page 3 of 4)

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory Description	Total Units Required	Location Used			GFE Units Available
			Factory	ETR	WTR	
162	Pneumatic skid launch	3		2	1	2
*163	Propellant or pneumatic control console	7	1	4	2	5
164	Battery checkout kit	2		1	1	2
168	Spacecraft simulator	3	1	1	1	
169	Space tug simulator	3	1	1	1	
172	Stage transport preparation GN_2 purge unit	1		1		1
173	Stage weigh and balance kit	3	1	1	1	
174	Star tracker simulator	3	1	1	1	
175	Static desiccant kit	8	2	4	2	
176	Subsystem monitoring consoles	9		6	3	6
177	Tape recorder component test set					
178	Television system checkout kit					
180	Environment conditioning unit	4	1	2	1	
181	Tilt table handling kit	4	1	2	1	
182	Tractor -- transporter	5	1	2	2	5
183	Transporter	7	1	4	2	
184	Tug support kit (vertical)	3	1	1	1	
*185	Umbilical system	7	1	4	2	
189	Voice and timing system	2		1	1	1
190	Wide band magnetic tape recorder	4		2	2	2
191	Workstand -- kit	10	2	6	4	
192	Security vehicle	6		3	3	6
301	Simulation flight test computer programs	3	1	1	1	
302	Ground checkout computer programs	3	1	1	1	
304	Ground checkout tug processing facility computer prog.	3	1	1	1	

*Factory units shipped to field centers for reuse.

Table 4-3 (Page 4 of 4)

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules: Install one pad at WTR; Use GSE from factory Description	Total Units Required	Location Used			GFE Units Available
			Factory	ETR	WTR	
305	Ground support self-check computer programs	3	1	1	1	
306	Launch countdown computer programs	2	1	1	1	
307	Support software computer programs	2	1	1	1	
308	AEDC interface cable kit	1				
309	Tug test cell holding fixture	1				
310	AEDC interface junction box	1				
311	Test software computer program	1				
312	Mission control tug subsystem software	1				
313	DOD mission control status & monitoring station (Totally GFE)	7				7
314	NASA mission control status monitoring stations (Totally GFE)	7				7

*Factory units shipped to field centers for reuse.

KSC/WTR launch sites. Variations in dollar value of the logistics inventory have been expressed in the maintenance and refurbishment inputs to the cost model.

Spares

The maintainability analyses have addressed unscheduled maintenance in terms of spares requirements. This applies risk-of-failure analysis methods to prediction of spares requirements and maintenance manhours. All predictions were made by the same methods, thus assuring that the data present the proper range of relative performance for purposes of preferential evaluation and ranking with regard to unscheduled maintenance.

Spare parts costs estimates were introduced into the cost model in terms of initial spares and depot maintenance, and measured in terms of equivalent units of production subsystem hardware costs. The initial spares are required to repair any failure present in a returning Tug for the first five flights. The estimates for subsystems assumed at least one of each replaceable item plus several additional parts for those items having a high failure risk and a long flow time for depot overhaul. The comparison of costs for the separate subsystems are determined. The cost comparison and method of calculation is shown in Section 6.11.4.1 of Volume 6.

Section 5
PROGRAMMATICS AND COST

5.1 VEHICLE MANUFACTURING SUMMARY

The vehicle manufacturing plan of the Space Tug contains the manufacturing support of the Tug DDT&E requirements, the production manufacturing plan (including peak rate charts), manufacturing flow plans, tooling required to manufacture the Tug at the prescribed rate, and the facilities that will be required to accomplish the task. The problem areas, special processes required, summary analysis, and manufacturing philosophy engendered into the manufacturing plan as included in Volume 8. The manufacturing breakdown is shown in Figure 5.1.

5.1.1 Plan/Flow/Time

The manufacturing plan flow/time elements used for the manufacture of the Space Tug is based on the following key factors:

- Low production requirements.
- Minimum DDT&E costs.
- Low production manufacturing costs.
- Low early year funding.
- Low manufacturing rate requirement.
- Test article requirements support.
- Utilization of existing capital equipment, GSE, and facilities.
- High reliability and reuseable requirements of the Space Tug.

The above noted key factors were considered and incorporated into the manufacturing plan with the principal motivating factor being the high reliability and reusability requirement.

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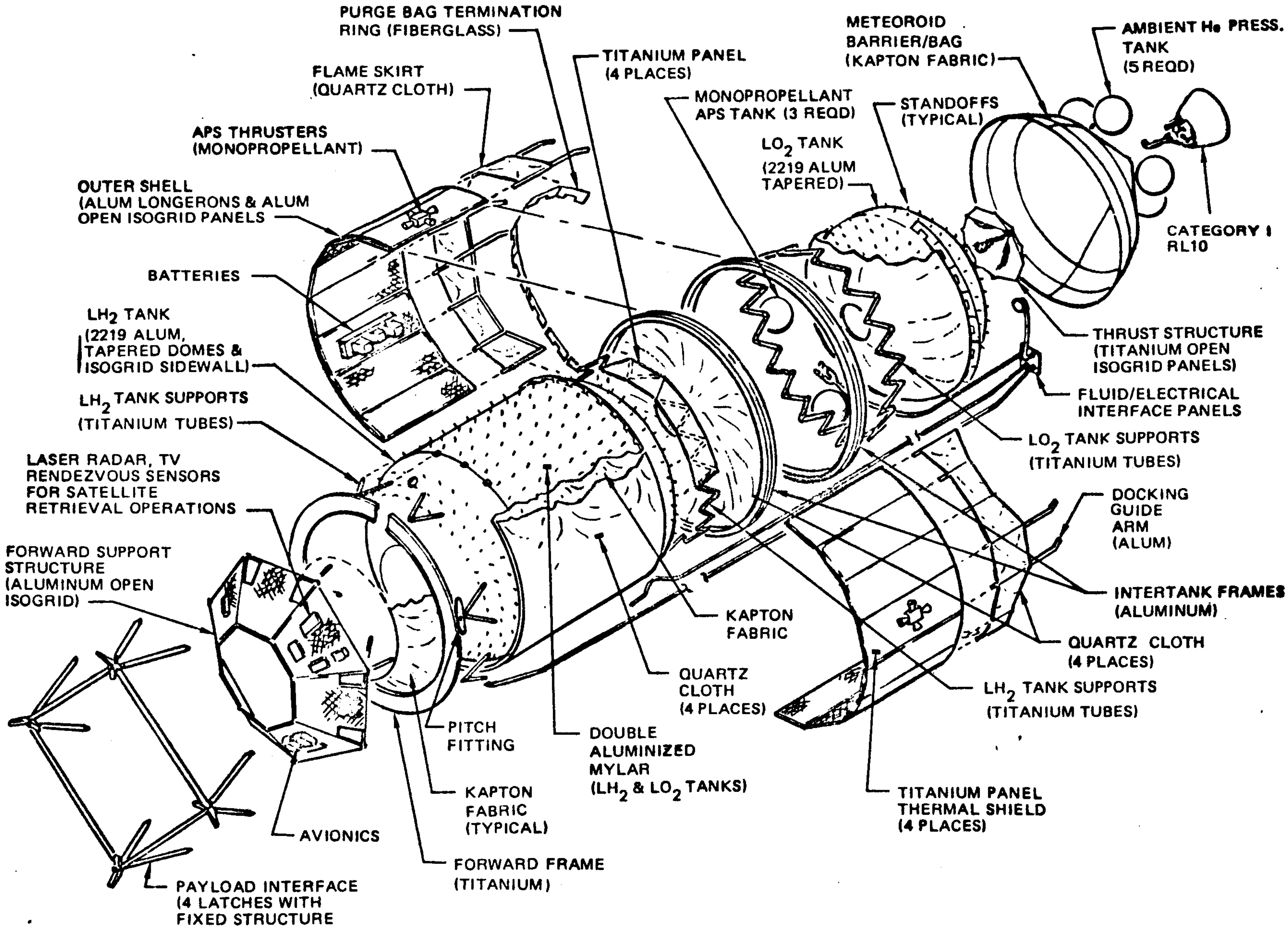


Figure 5-1. Space Tug Configuration – Option 1

5.1.2 Manufacturing Requirements

This section has been divided into two parts to separate the manufacturing requirements for major test articles from those needed for the production of flight articles. No dedicated flight test articles are planned for this program. Schedule requirements for the major test articles are presented in Volume 8, Section 1.2. Wherever practical or feasible from a schedule standpoint, manufactured test components will be fabricated during tool proofing to lower the program cost, reduce planning effort, increase and reduce tooling setup times for test components.

5.1.2.1 Major Test Articles

The following test articles will be produced: structural test articles, propulsion test vehicle, integrated avionics test unit, flight control simulation, and flight support equipment.

5.1.2.2 Flight Articles

MDAC does not plan to provide dedicated flight test articles, as the high reliability and reusability stressed in the initial design and proven in development tests, will ensure flight worthy hardware. A total of 13 flight vehicles will be produced. Manufacture of the flight articles is described elsewhere in this report together with the production flow for test, integration, installation, and checkout.

5.1.3 Manufacturing Schedule and Flow

The manufacturing schedule is based on the production schedule, shown in Volume 8, Section 1.3, which is the basis also for the manufacturing flow charts, lead time setback charts, and first tool usage requirements.

The manufacturing flow schedule shown in Figure 5-2 begins with engineering design effort at ATP, and defines the sequence of activities by procurement, planning, tooling, and manufacturing through detail fabrication, subassembly

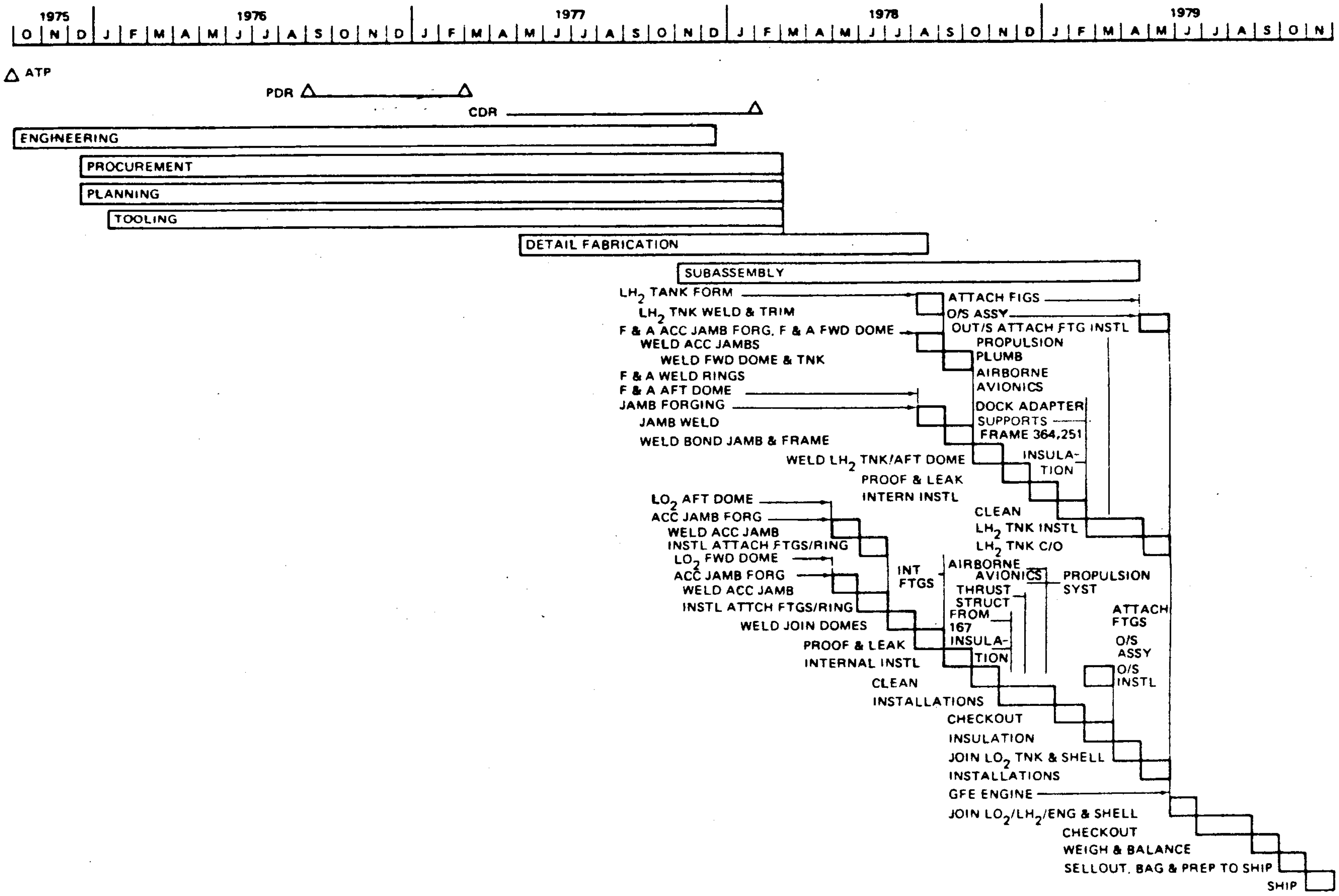


Figure 5-2. Space Tug Manufacturing Flow Schedule – Option 1

and assembly, integration and installation, and through final checkout and preparation for shipment. Major inspection points such as proof and leak check are also shown in this chart.

The peak rate tree chart presented in Figure 5-3 shows both detailed manufacturing steps and the units in flow at peak production rate.

Additional detailed manufacturing sequence flow charts are contained in the manufacturing plan which is discussed in detail in Volume 8, Section 4.1.3.

5.1.4 Manufacturing Plan

The manufacturing plan outlined in this section is structured as follows:

- Fabrication and subassembly (structures) plan and flow plans.
- Tank bonding and insulation plan and flow plans
- Final assembly and final joining plan and flow plans
- Propulsion fabrication and subassembly plan and flow plans
- Avionics fabrication and subassembly and installation plan and flow plans.
- Production acceptance test plan.

5.1.4.1 Fabrication and Subassembly Plan (Structures)

The fabrication and subassembly requirements for the manufacture of structural components comprising the Space Tug are state-of-the-art and will not require the development of unique manufacturing processes. Low cost "soft" tooling i.e., layout templates, router/blocks, drop hammer dies, etc., will be used extensively where practical. The LH_2 and the LO_2 domes will be subcontracted to a vendor that currently has the capability to manufacture a one piece dome.

The fusion joining of the LH_2 tanks and the LO_2 tanks will be accomplished using the latest Tig welding techniques. Note: The welding process employed in the manufacture of the Space Tug LH_2 and LO_2 tanks is fully discussed in Volume 8, Section 4.5 Summary Analysis/Philosophy.

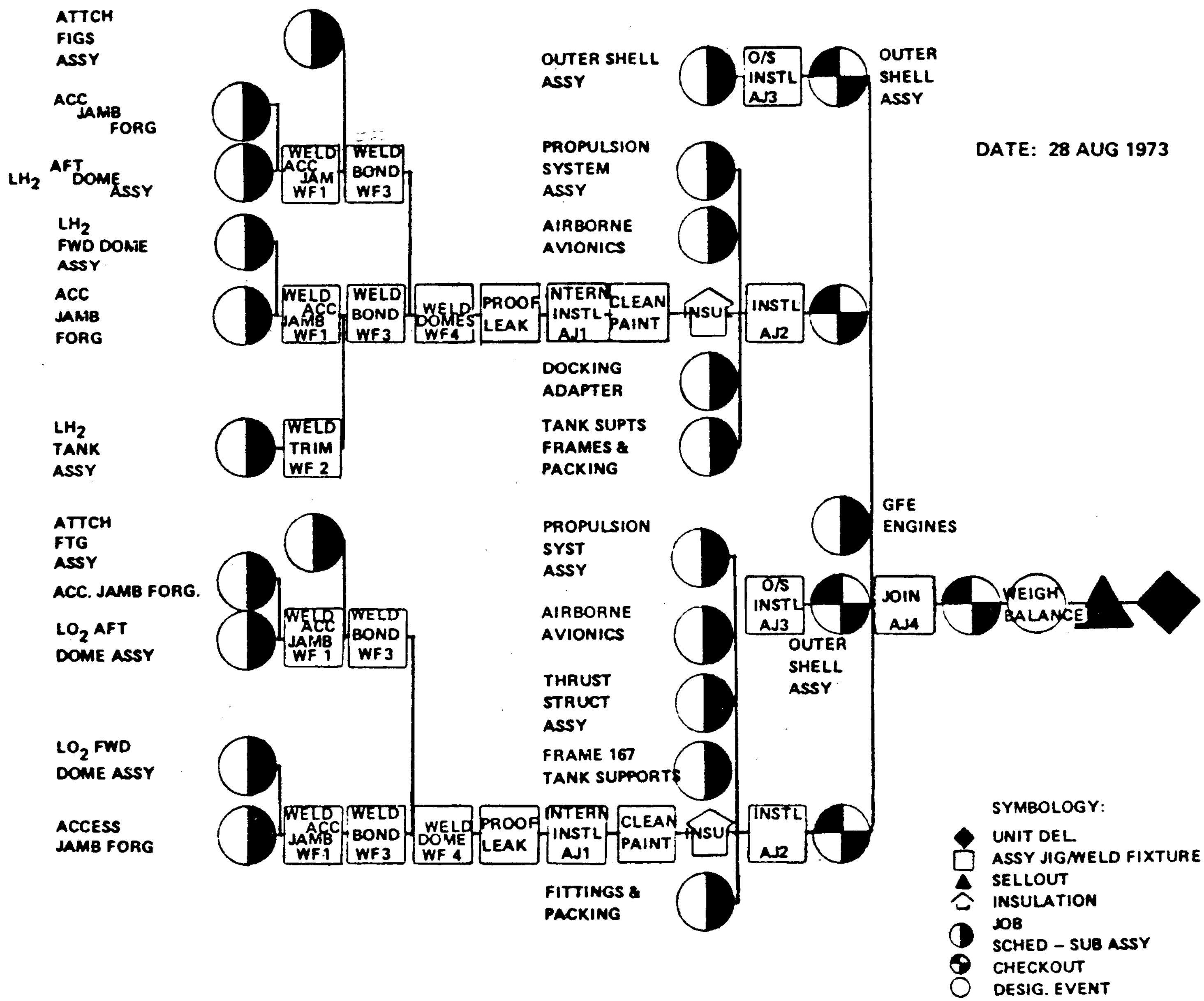


Figure 5-3. Space Tug System Study (Cryogenic) – Peak Rate Tree Chart (Max Rate 4 Per Year) – Option 1

The manufacturing requirements for each of the Space Tug components are outlined in the Tug fabrication flow plans, see typical flow plans Figure 5-4.

5.1.4.2 Tank Bonding Plan

The tank bonding and insulation plan for the bonding of the insulation and the Kapton purge bad stand-offs is delineated in the Space Tug fabrication flow plan detailed in Volume 8.

5.1.4.3 Final Assembly and Final Joining Plan

The final assembly and final joining line sequence flow are outlined in the Final-assembly/joining flow plan, Figure 5-5. The LO_2 and the LH_2 tanks are built up as modular assemblies in the horizontal mode. The LO_2 and the LH_2 subassembly jigs are then mated per leader pins and index points, and the final joining, installations, and checkout are accomplished.

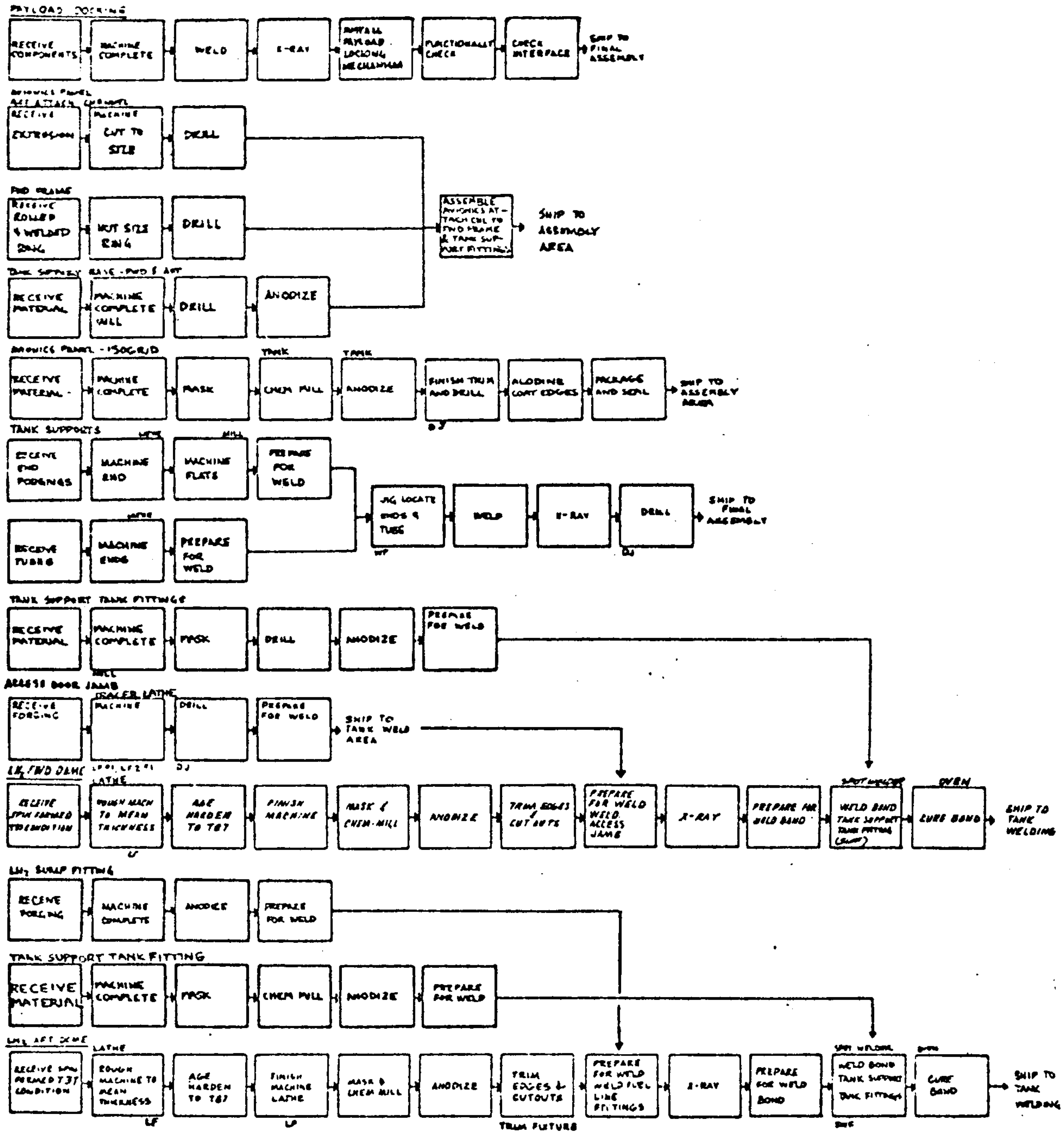


Figure 5-4. Space Tug Fabrication Flow Plan—Option 1 (Page 1 of 2)

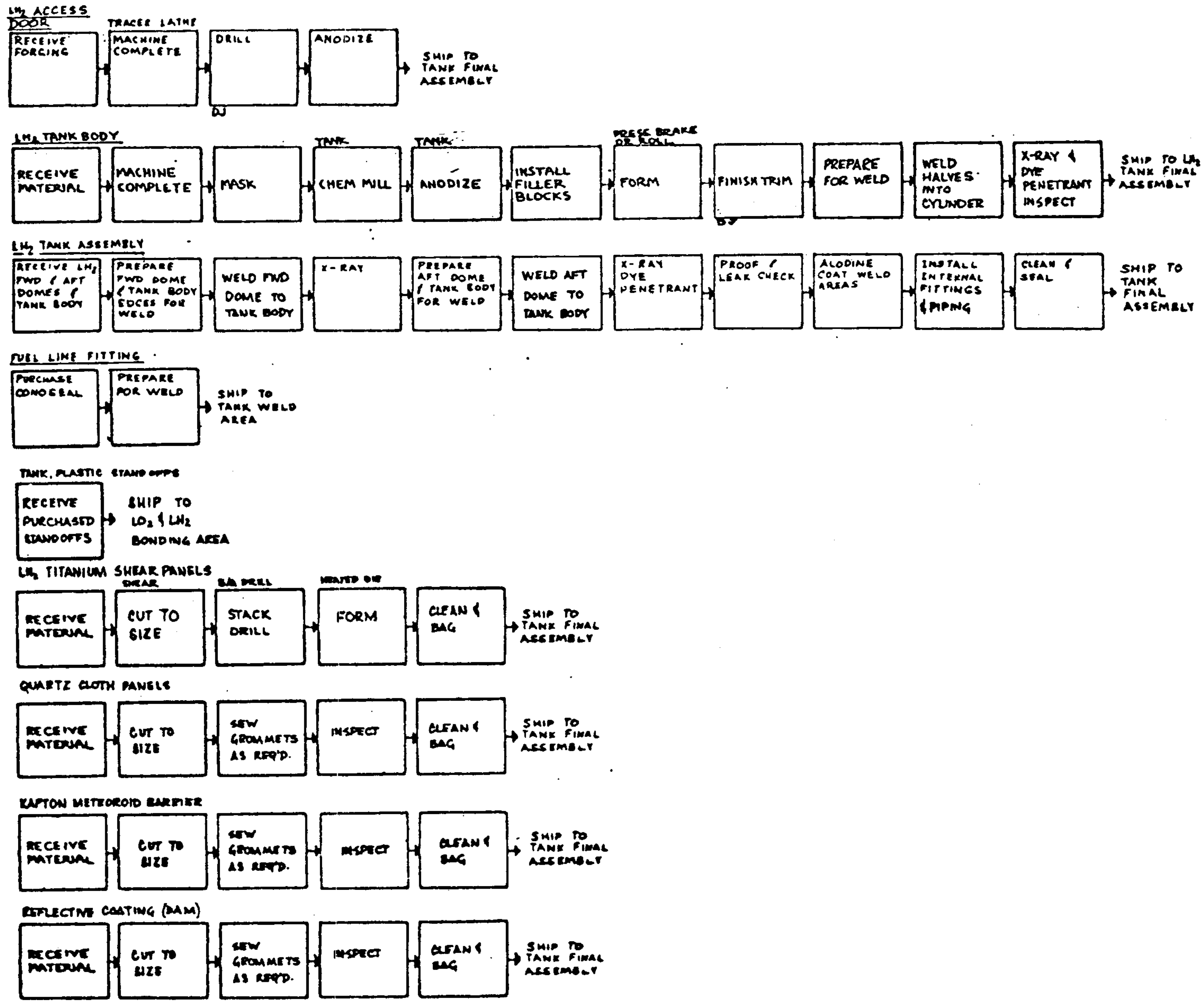


Figure 5-4. Space Tug Fabrication Flow Plan—Option 1 (Page 2 of 2)

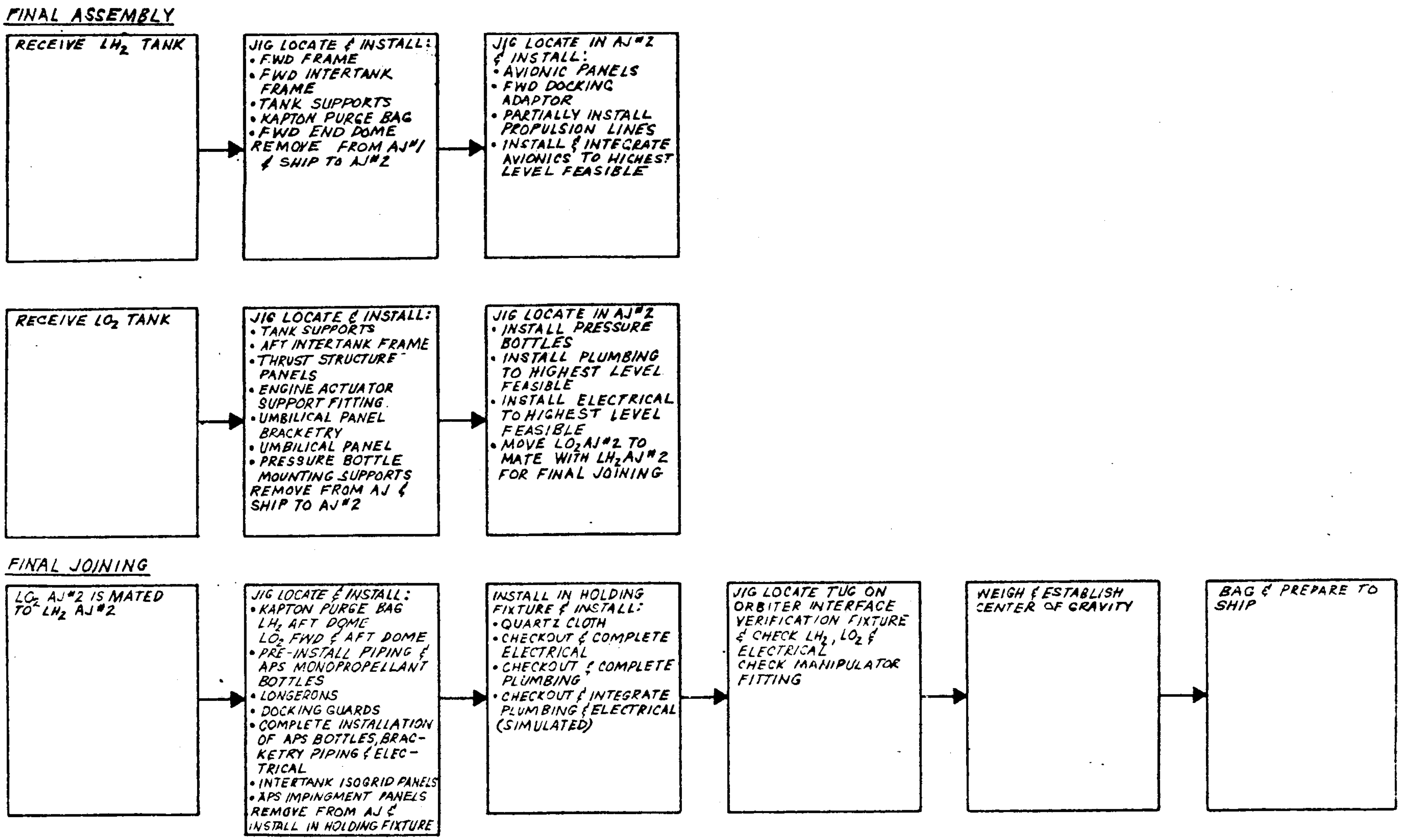


Figure 5-5. Space Tug Final – Assembly/Joining Flow Plan – Option 1

5.2 FACILITIES

The requirements developed by operations analysis in the areas of manufacturing, test, integration, C/O, launch, recovery, refurbishment, and storage were matched against existing, modified, and new facilities on the basis of availability, compatibility, and cost.

It was determined that facilities are not configuration-sensitive; cost is not a determinate factor in selection since existing facilities can be utilized for most requirements.

Tug facilities at ETR will be satisfied by one new building and by modification and refurbishment of existing buildings and by use of Orbiter facilities that can be expanded or adapted to include Tug service.

At WTR construction of a new payload processing facility together with use of programmed Shuttle facilities expanded to satisfy Tug needs will provide the support required.

Manufacturing facilities will be based on existing MDAC plant and equipment at Huntington Beach, California, modified and augmented by autoclaves-presses, and miscellaneous low-cost equipment as required to produce the Tug.

Production testing will be done at Huntington Beach. Some vehicle tests will be accomplished at NASA facilities at Huntsville and AEDC facilities at Tullahoma. Only such GSE as is needed for handling, loading, and other Tug-peculiar requirements will be provided at test facilities.

Tabulations of all facility requirements, their cost, location, and lead times are shown in Tables 5-1 and 5-2.

5.3 VEHICLE TEST PROGRAM

A development test program envelopes SR&T; development and qualification testing of parts, components, subassemblies, and assemblies of subsystems; reliability testing of selected items; repairability/maintainability testing of the smaller items; development, qualification, maintenance, and maintainability testing of major or vehicle level test articles; and flight testing of the completed CEI.

Table 5-1

OPERATIONAL FACILITIES SUMMARY

Facility	Origin	KSC	WTR
Tug Processing Facility	Modified KSC Bldg M7-355	$500,000	
DOD Payload Processing Facility	New	500,000	
Payload Processing Facility	New		$750,000
Maintenance and CO Facility	Modified Shuttle Facility	10,000	
Maintenance and CO Facility	Modified Shuttle Facility		10,000
Launch Service Structure	Modified Shuttle Facility	350,000	
Launch Service Structure	Modified Shuttle Facility		350,000
Launch Control Center	Modified Shuttle Facility	10,000	
Launch Control Center	Modified Shuttle Facility		0
Safing Facility	Modified Shuttle Facility	0	
Safing Facility	Modified Shuttle Facility		0
Storable Propellant Facility	Modified Shuttle Facility	0	
Storable Propellant Facility	Modified Shuttle Facility		0
Vertical Assembly Building	Modified Shuttle Facility	10,000	
Vertical Assembly Building	Modified Shuttle Facility		10,000
		1,380,000	1,120,000

Table 5-2

SPACE TUG STUDY

ADDITIONAL MANUFACTURING FACILITIES

	Description	Lead Time	ROM Cost Option 1 and 3	ROM Cost Option 2
1.	Aging oven 20 ft x 20 ft x 8 ft (325°F)	6 months	$ 30,000	
2.	Autoclave 16 ft dia x 12 ft long (600°F)	10 months	130,000	
3.	Chem-mill facility 2 tanks 20 ft x 20 ft x 12 ft	10 months	200,000	
4.	Anodize facility 20 ft x 20 ft x 10 ft tanks	4 months	200,000	
5.	Clean room/10 ton bridge crane 5,000 sq ft (100,000 class)	8 months	250,000	
6.	Acoustic emission test equipment (PATE)		150,000	
7.	Acoustic emission test equipment (PATE)		75,000	
				$1,035,000
8.	Curing oven 16 ft x 16 ft x 8 ft (600°F)	6 months		60,000
	Total		1,035,000	1,095,000

TEST FACILITIES

		NASA	DOD
1.	MDAC Huntington Beach Laboratories	0	0
2.	NASA Huntsville high vacuum facility	0	250,000
3.	AEDC Tullahoma Mark 4 chamber	1,250,000	0

The acquisition of assurance of reusability of the cryogenic Space Tug through equipment life, maintainability, and/or refurbishment, begins with design and continues through component and vehicle level testing to mission operations. Design for high reliability and judiciously planned and implemented testing must be used to ensure the specified reusability and life of the Space Tug.

The most cost-effective program combines four philosophies pertinent to design, analyses, and test.

A. Select existing hardware that is shown to have survived space flight.

B. Design new subsystem hardware to survive an economically reasonable portion of Tug life.

C. Determine through reliability analyses that component reliability meets Tug requirements and that failures which may occur must be considered random failures.

D. Determine that a component/subassembly/assembly/subsystem cannot be removed and replaced through scheduled or unscheduled maintenance; design for survival through Tug environmental criteria beyond expected life.

The majority of the components intended for this configuration have been developed for use in previously produced space vehicles, are standard components qualified for space vehicle applications, or will require little modification to meet Space Tug specifications. For those components requiring new or further development or requalification, an economically feasible population will be selected for the appropriate type of testing. Further, the level of hardware assembly at which verification of a given item can be adequately achieved — i.e., component, subassembly, assembly — will be evaluated. To the maximum extent possible, qualification of hardware included in the design will be achieved through means other than testing, i.e., analysis, inspection, demonstration, or simulation. Emphasis will be placed on repairability within each analysis or during testing.

Combination of design selection of high-reliability/long-life components and parts and the component verification approach outlined above should yield an approximate 10-percent reduction of operational maintenance and refurbishment costs. DDT&E costs will be higher due to testing and its associated population requirements to provide reliability and life; however, this cost is non-recurring and will produce a reduction in recurring costs by lowering the incidence of both scheduled and unscheduled maintenance and refurbishment.

5.3.1 Vehicle Ground Test Summary

Tests to be conducted with the major test articles are summarized in Table 5-3. The testing program is designed to provide the maximum confidence possible consistent with minimum DDT&E funding of this option. Test descriptions and estimates are provided in Volume 8.

5.3.2 Flight Test

Flight-test objectives are aimed at verifying that the Space Tug can perform assigned missions within the specified mission envelope of performance and time requirements.

The first produced Tug will be equipped with special flight-test instrumentation in support of the following objectives:

A. Propellant settling.
B. Propellant utilization.
C. Propellant feedline and engine thermal conditioning.
D. Propellant conditioning.
E. Zero-g heat transfer.
F. Avionics cold plate temperature stabilization.
G. Vibration levels of selected critical installations.

Information will be obtained from this instrumentation during the first two flights flown by this Tug. The flights will carry spacecraft for orbital placement. Following termination of the second flight, the flight-test instrumentation will be removed and the Tug processed through a normal turnaround cycle. This Tug will then continue normal operations within the fleet.

5.4 SCHEDULE SUMMARY (NASA ACQUISITION)

The schedule for Space Tug Option 1 (Figure 5-6) is based on a Phase C/D design development and operations authority to proceed (ATP) in October 1975. Design development, test, and evaluation (DDT&E) requires 54 months and is

Table 5-3

VEHICLE TEST

Test	NASA	DOD	IOC CHG
Pressure Cycle Tanks (Development)	X	X	X
Pressure Burst Tanks (Development)	X	X	X
Pressure Cycle/Proof Tanks and Static Loading of Remainder of Structures Subsystems (Qualification)	X	X	X
Maintenance ($\bar{M}$) Procedures Verification (DT&E, IOT&E) - Development Fixture	X	X	X
Maintainability (M) Evaluation - Development Fixture	X	X	X
Propulsion Test Vehicle - Cold Flow (CAT I RL10 Engine)	X	X	X
Propulsion Test Vehicle - Static Firing (Other Than CAT I RL10)			
Maintainability ($\underline{M}$) Evaluation - PTV	X	X	X
Integrated Avionics Test Unit (IATU) (DT&E, IOT&E)	X	X	X
Maintainability ($\underline{M}$) Evaluation - IATU	X	X	X
Flight Control Simulation (Deployment Only)	X	X	X
Flight Control Simulation (Deployment and Retrieval)			
Transportation and Handling Procedures Verification, Flight-Test Article (DT&E, IOT&E)	X	X	X
Thermal			
EMC - Flight-Test Article, Manufacturing	X	X	X
EMC - First Delivered Tug, ETR	X	X	X
EMC - First Delivered Tug, WTR	X	X	X
$\bar{M}$ - Flight-Test Article, ETR	X	X	X
$\bar{M}$ - Flight-Test Article, WTR	X	X	X
Flight Support Equipment with an IVU	X	X	X
Flight Support Equipment with an IVU and the Orbiter (Egress-Ingress)	X	X	X
Flight-Test Operations Egress-Ingress Maneuver Verification Using the IVU	X	X	X
Flight Test Operations-Two Flights with Operational Missions	X		X
Flight-Test Operations - Two Flights, Dedicated		X	
Flight-Test Operations - One Flight with Operational Mission			
Flight-Test Operations - One Flight, Dedicated			

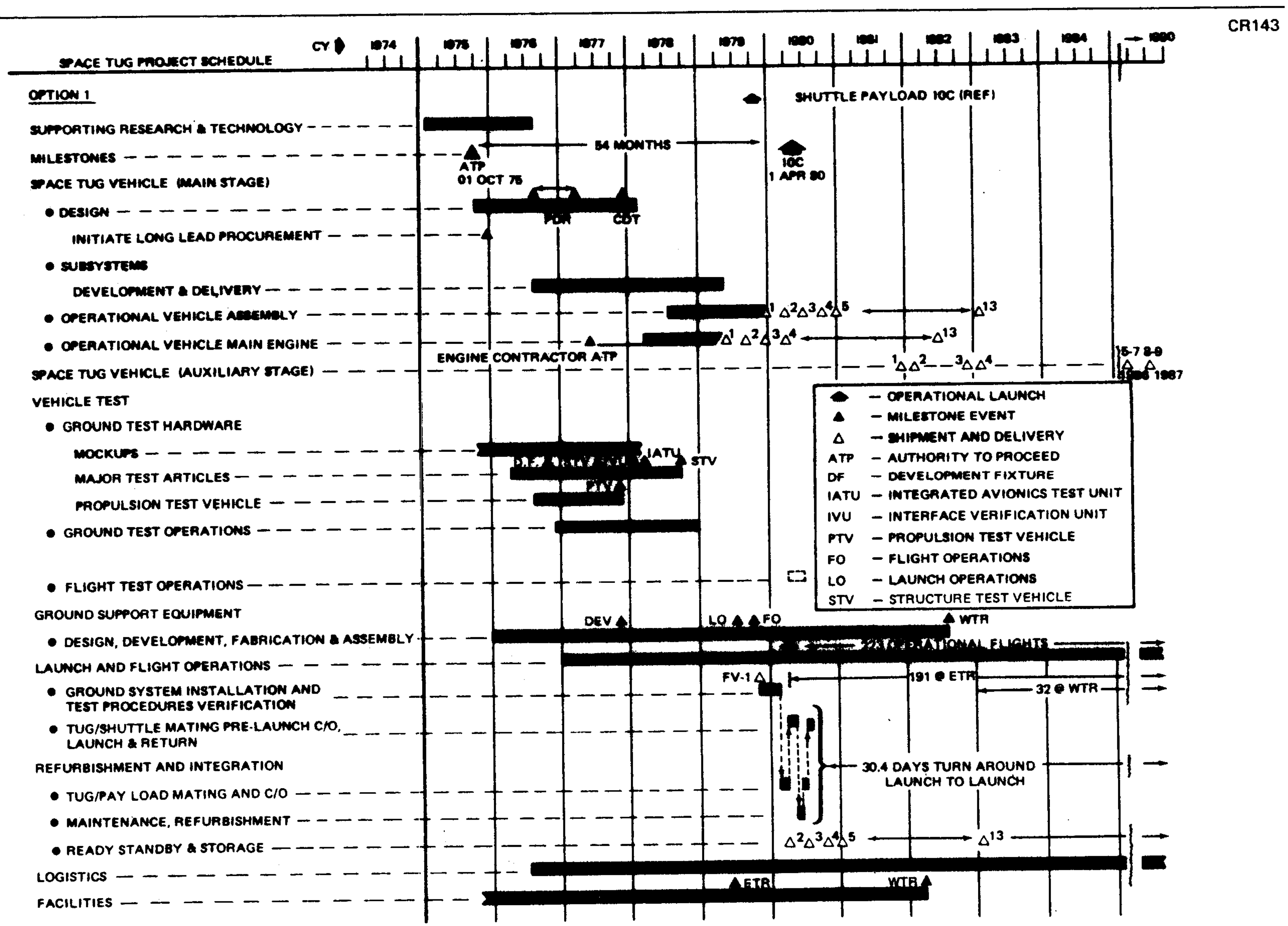


Figure 5-6. Space Tug Option 1 Schedule

complete at the first Space Tug operational launch on April 1, 1980. Flight operations of 10.7 years are assumed to begin with the first operational launch and be completed in 1990.

Completion of Space Tug preliminary design review (PDR) is scheduled for March 1977, to establish firm vehicle configurations. A critical design review (CDR) will be completed in December 1977 to ensure that design requirements have been met.

The ground test program will use subsystem models for concept and design development and design qualification. Qualification of subsystems will be complete in January 1979, 39 months after ATP. System-level test articles will be used in the ground test program for subsystem integration and interface verification activities. Two Space Tug vehicles are required at IOC to support the initial requirement of three flights in the first year of operations. A total of 13 vehicles are produced and delivered over a period of three years. Vehicles are stored at the launch facility and used as required to support launch and refurbishment operations.

Operational flights start at IOC, April 1, 1980, and are completed with the 223rd flight in 1990. One hundred and ninety-one flights are launched from ETR and 32 flights are launched from WTR. No dedicated flight-test operations are required.

5.5 COST SUMMARY (NASA ACQUISITION)

Summary costs for this program option are presented in the following charts:

A. Summary Cost Tabulation

B. Cost Summary

C. Cost Per Flight Data Sheets.

Reference is made to Volume 8, Book 1 for detail cost information.

The Summary Cost Tabulation (Table 5-4) is derived from the LEADER II Cost Model printout. The Cost Summary (Figure 5-7) presents a Technical Summary, a Schedule Summary, an Annual Funding Summary, and a Cumulative Funding Summary. The Cost-Per-Flight Data Sheets have been prepared in accordance with

Table 5-4

PROGRAM OPTION NO. 1

SUMMARY COST TABULATION

1973 DOLLARS IN MILLIONS

Total Program Costs		Unit Costs	
DDT&E	$197.05	Vehicle Main Stage	
Production	179.57	First Prod Unit - Hardware	$14.44
		Average Unit (including Support)	12.22
Operations	200.81		
		Vehicle Auxiliary Stage	
Total	$577.43		
		Average Unit (including Startup)	2.30
		Average Cost per Flight	
		Mode 1 - NASA	0.90
		Mode 1 - DOD	0.90
		Mode 2 - NASA	12.89
		Mode 2 - DOD	Not required
		Mode 3 - NASA	3.20
		Mode 3 - DOD	Not required

NASA Direction (Reference: Letter PD-TUG-P(015-74), dated August 3, 1973, from J. A. Stucker, Manager, Program Planning and Control, to A. G. Orillion, COR, PD-TUG-C).

5.6 SCHEDULE SUMMARY (DOD ACQUISITON)

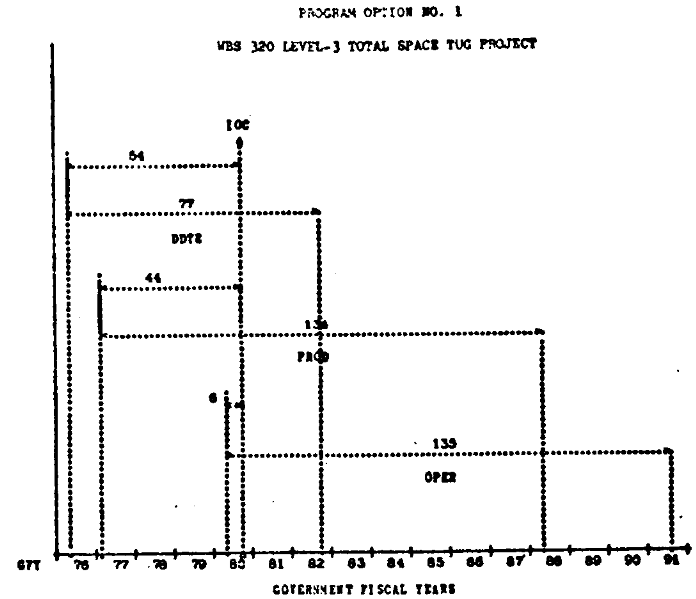
Submittal of these data for Program Option 1 has been deferred until after the September data dump, by agreement with the NASA and USAF/SAMSO study COR's.

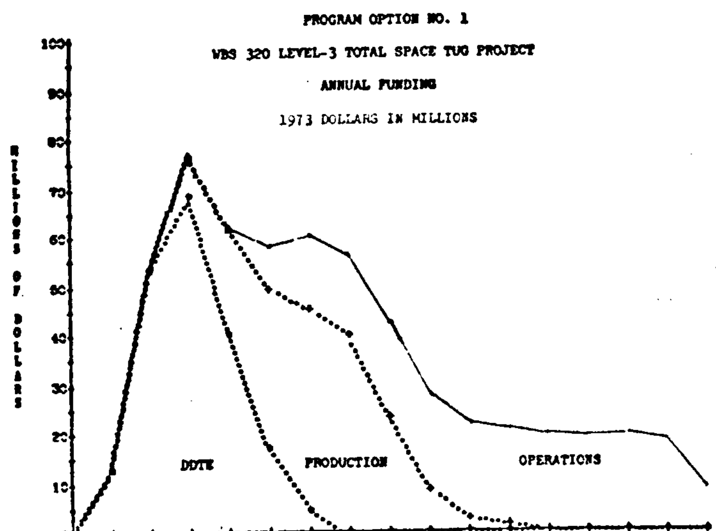
5.7 COST SUMMARY (DOD ACQUISITION)

Submittal of these data for Program Option 1 has been deferred until after the September data dump, by agreement with the NASA and USAF/SAMSO study COR's.

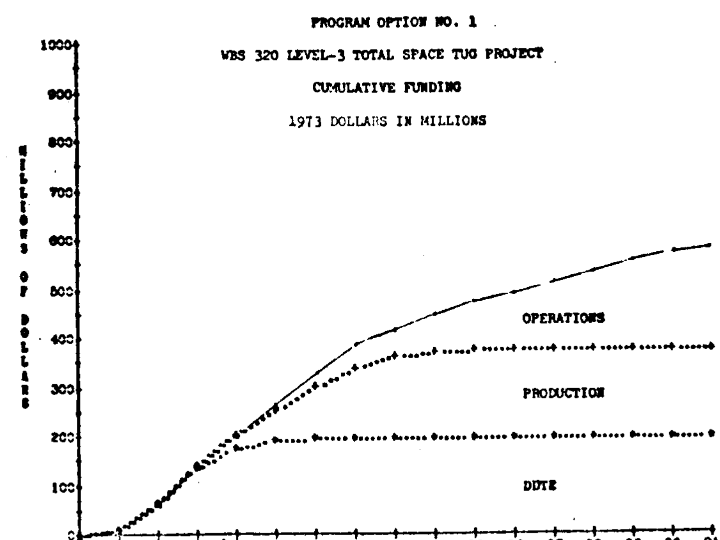
TE[illegible] CHARACTERISTICS - OPTION NO. 1
WBS 320 TOTAL STAGE TUG PROJECT

MAJOR HARDWARE	
SPACE TUG VEHICLE MAIN STAGE	- 13 VEHICLES
SPACE TUG VEHICLE AUXILIARY STAGE	- 9 STAGES
OTHER SYSTEM ELEMENTS	
PROJECT MANAGEMENT	
SYSTEMS ENGINEERING AND INTEGRATION	
LOGISTICS	- TRANSPORTATION, TRAINING, SIMULATION
FACILITIES	- FACTORY, TEST, ETR, WTR
GROUND SUPPORT EQUIPMENT	- FACTORY, ETR, WTR
VEHICLE TEST	- PTV, MAJOR TEST ARTICLES
LAUNCH OPERATIONS - WTR	- 32 LAUNCHES
LAUNCH OPERATIONS - ETR	- 190 LAUNCHES
FLIGHT OPERATIONS - NASA*	- 117 FLIGHTS
FLIGHT OPERATIONS - DOD	- 105 FLIGHTS
REFURBISHMENT AND MAINTENANCE - WTR	- 32 REFURBISHMENTS
REFURBISHMENT AND MAINTENANCE - ETR	- 190 REFURBISHMENTS





GFY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT-E	12.9	53.1	63.5	40.6	17.1	4.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
PROD	.0	.9	8.2	21.4	32.1	41.0	39.8	23.2	8.5	2.8	1.6	.4	.0	.0	.0	.0
OPER	.0	.0	.0	.0	8.8	15.2	15.9	19.0	19.0	19.0	19.0	19.0	19.0	19.0	18.8	9.1
TOTAL	12.9	54.0	76.7	62.0	58.0	60.6	55.8	42.2	27.5	21.8	20.6	19.4	19.0	19.0	18.8	9.1



GFY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT-E	13	66	135	175	192	197	197	197	197	197	197	197	197	197	197	197
PROD	0	1	9	30	63	104	143	167	175	178	179	180	180	180	180	180
OPER	0	0	0	0	9	24	40	59	78	97	116	135	154	173	192	201
TOTAL	12	66	143	205	264	325	380	423	450	472	492	512	531	550	569	578

Figure 5-7. Cost Summary – Program Option No. 1

Table 5-5

AVERAGE COST PER FLIGHT, MODE 1 - REUSABLE BASIC TUG

	AGENCY NASA PROGRAM OPTION 1	
LAUNCH OPERATIONS		$ 198,301
Tug/Shuttle mating and checkout	$ 18,656	
Tug/Payload mating and checkout	26,651	
Prelaunch checkout	27,860	
Countdown	25,444	
Propellant and gases	6,410	
Post flight safing	29,317	
Site services and support	63,963	
MAINTENANCE AND REFURBISHMENT		$ 230,219
Scheduled maintenance and refurbishment	$ 34,647	
Unscheduled maintenance and refurbishment	10,661	
Tug engine maintenance and refurbishment	11,538	
Tug vehicle spares	45,966	
Tug engine spares	6,410	
Post maintenance checkout	2,644	
Refurbishment requirements planning	10,661	
Depot maintenance	107,692	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 428,520
FLIGHT OPERATIONS		$ 311,000
Mission planning	$ 46,000	
Flight control	201,000	
Flight evaluation	43,000	
Flight software	21,000	
OPERATIONS SUPPORT		$ 156,154
Airborne software update	$ 10,085	
GSE maintenance	20,000	
Sustaining engineering	50,513	
Program management	33,162	
Transportation and handling	1,453	
Inventory control and warehousing	21,197	
Facilities maintenance	5,470	
GSE software update	14,274	
EXPENDABLE VEHICLE MAIN STAGE		$ 0
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$ 895,674

Table 5-6

AVERAGE COST PER FLIGHT, MODE 2 - EXPENDED TUG

	AGENCY NASA PROGRAM OPTION 1	
LAUNCH OPERATIONS		$ 198,301
Tug/Shuttle mating and checkout	$ 18,656	
Tug/Payload mating and checkout	26,651	
Prelaunch checkout	27,860	
Countdown	25,444	
Propellant and gases	6,410	
Post flight safing	29,317	
Site services and support	63,963	
MAINTENANCE AND REFURBISHMENT		$ 0
Scheduled maintenance and refurbishment	$	
Unscheduled maintenance and refurbishment		
Tug engine maintenance and refurbishment		
Tug vehicle spares		
Tug engine spares		
Post maintenance checkout		
Refurbishment requirements planning		
Depot maintenance		
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 198,301
FLIGHT OPERATIONS		$ 311,000
Mission planning	$ 46,000	
Flight control	201,000	
Flight evaluation	43,000	
Flight software	21,000	
OPERATIONS SUPPORT		$ 156,154
Airborne software update	$ 10,085	
GSE maintenance	20,000	
Sustaining engineering	50,513	
Program management	33,162	
Transportation and handling	1,453	
Inventory control and warehousing	21,197	
Facilities maintenance	5,470	
GSE software update	14,274	
EXPENDABLE VEHICLE MAIN STAGE		$12,220,000
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$12,885,455

Table 5-7

AVERAGE COST PER FLIGHT, MODE 3 - EXPENDED KICK STAGE

		AGENCY NASA PROGRAM OPTION 1
LAUNCH OPERATIONS		$ 198,301
Tug/Shuttle mating and checkout	$ 18,656	
Tug/Payload mating and checkout	26,651	
Prelaunch checkout	27,860	
Countdown	25,444	
Propellant and gases	6,410	
Post flight safing	29,317	
Site services and support	63,963	
MAINTENANCE AND REFURBISHMENT		$ 230,219
Scheduled maintenance and refurbishment	$ 34,647	
Unscheduled maintenance and refurbishment	10,661	
Tug engine maintenance and refurbishment	11,538	
Tug vehicle spares	45,966	
Tug engine spares	6,410	
Post maintenance checkout	2,644	
Refurbishment requirements planning	10,661	
Depot maintenance	107,692	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 428,520
FLIGHT OPERATIONS		$ 311,000
Mission planning	$ 46,000	
Flight control	201,000	
Flight evaluation	43,000	
Flight software	21,000	
OPERATIONS SUPPORT		$ 156,154
Airborne software update	$ 10,085	
GSE maintenance	20,000	
Sustaining engineering	50,513	
Program management	33,162	
Transportation and handling	1,453	
Inventory control and warehousing	21,197	
Facilities maintenance	5,470	
GSE software update	14,274	
EXPENDABLE VEHICLE MAIN STAGE		$ 0
EXPENDABLE VEHICLE AUXILIARY STAGE		$2,300,000
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$3,195,674

Table 5-8

AVERAGE COST PER FLIGHT, MODE 1 - REUSABLE BASIC STAGE

		AGENCY DOD PROGRAM OPTION 1
LAUNCH OPERATIONS		$ 201,648
Tug/Shuttle mating and checkout	$ 18,994	
Tug/Payload mating and checkout	27,134	
Prelaunch checkout	28,223	
Countdown	26,044	
Propellant and gases	6,286	
Post flight safing	29,847	
Site services and support	65,120	
MAINTENANCE AND REFURBISHMENT		$ 230,168
Scheduled maintenance and refurbishment	$ 35,274	
Unscheduled maintenance and refurbishment	10,853	
Tug engine maintenance and refurbishment	11,238	
Tug vehicle spares	46,495	
Tug engine spares	6,286	
Post maintenance checkout	2,693	
Refurbishment requirements planning	10,853	
Depot maintenance	106,476	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 431,816
FLIGHT OPERATIONS		$ 313,000
Mission planning	$ 46,000	
Flight control	204,000	
Flight evaluation	42,000	
Flight software	21,000	
OPERATIONS SUPPORT		$ 155,620
Airborne software update	$ 9,905	
GSE maintenance	19,238	
Sustaining engineering	50,476	
Program management	32,762	
Transportation and handling	1,524	
Inventory control and warehousing	20,857	
Facilities maintenance	5,429	
GSE software update	15,429	
EXPENDABLE VEHICLE MAIN STAGE		$ 0
EXPENDABLE VEHICLE AUXILIARY STAGE		$ 0
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$ 900,436

Table 5-9

AVERAGE COST PER FLIGHT, MODE 2 - EXPENDED TUG

		AGENCY DOD PROGRAM OPTION 1
LAUNCH OPERATIONS		$_____
Tug/Shuttle mating and checkout	$_____	NONE REQUIRED
Tug/Payload mating and checkout	_____	
Prelaunch checkout	_____	
Countdown	_____	
Propellant and gases	_____	
Post flight safing	_____	
Site services and support	_____	
MAINTENANCE AND REFURBISHMENT		$_____
Scheduled maintenance and refurbishment	$_____	
Unscheduled maintenance and refurbishment	_____	
Tug engine maintenance and refurbishment	_____	
Tug vehicle spares	_____	
Tug engine spares	_____	
Post maintenance checkout	_____	
Refurbishment requirements planning	_____	
Depot maintenance	_____	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$_____
FLIGHT OPERATIONS		$_____
Mission planning	$_____	
Flight control	_____	
Flight evaluation	_____	
Flight software	_____	
OPERATIONS SUPPORT		$_____
Airborne software update	$_____	
GSE maintenance	_____	
Sustaining engineering	_____	
Program management	_____	
Transportation and handling	_____	
Inventory control and warehousing	_____	
Facilities maintenance	_____	
GSE software update	_____	
EXPENDABLE VEHICLE MAIN STAGE		$_____
EXPENDABLE VEHICLE AUXILIARY STAGE		$_____
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$_____

Table 5-10

AVERAGE COST PER FLIGHT, MODE 3 - EXPENDED KICK STAGE

		AGENCY DOD PROGRAM OPTION 1
LAUNCH OPERATIONS		$____
Tug/Shuttle mating and checkout	$____	
Tug/Payload mating and checkout	____	
Prelaunch checkout	____	
Countdown	____	NONE
Propellant and gases	____	REQUIRED
Post flight safing	____	
Site services and support	____	
MAINTENANCE AND REFURBISHMENT		$____
Scheduled maintenance and refurbishment	$____	
Unscheduled maintenance and refurbishment	____	
Tug engine maintenance and refurbishment	____	
Tug vehicle spares	____	
Tug engine spares	____	
Post maintenance checkout	____	
Refurbishment requirements planning	____	
Depot maintenance	____	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$____
FLIGHT OPERATIONS		$____
Mission planning	$____	
Flight control	____	
Flight evaluation	____	
Flight software	____	
OPERATIONS SUPPORT		$____
Airborne software update	$____	
GSE maintenance	____	
Sustaining engineering	____	
Program management	____	
Transportation and handling	____	
Inventory control and warehousing	____	
Facilities maintenance	____	
GSE software update	____	
EXPENDABLE VEHICLE MAIN STAGE		$____
EXPENDABLE VEHICLE AUXILIARY STAGE		$____
TOTAL AVERAGE PER FLIGHT COST (1973 $)		$____

5.8 PROGRAM MANAGEMENT FOR THE SPACE TUG PROJECT

MDAC's management approach to the Space Tug project is to apply the tools and techniques most appropriate to ensure project control at an acceptable cost level. Our approach includes reaffirming the Government's management requirements so that we can be appropriately responsive to their needs. MDAC's available management tools and techniques have evolved during extensive development and use with both NASA and DoD programs as well as on Douglas' commercial aircraft programs.

As demonstrated during the Space Tug Phase A Systems Study, the MDAC management philosophy emphasizes "cost planning." This cost planning, which will continue throughout all phases of program definition and beyond, will result in cost-awareness/cost-avoidance attitudes that are essential to effective project cost control. Cost planning is not limited to the prime contractor's role, but will extend through the working relationships to the Government and to the suppliers to establish clear-cut cost objectives and the management plans appropriate for achieving these objectives.

MDAC's cost-awareness/cost-avoidance philosophy on Space Tug emphasizes the identification of and the avoidance of all unnecessary costs. This will call for close contractor/Government working relationships and teamwork to define and manage to only those effective project requirements. The net effect of the application of this philosophy is to develop the Space Tug with only the necessary equipment, material, and labor, and hence at lower costs.

Actions that highlight the MDAC low-cost management approach on Space Tug include:

- Develop (in concert with the customer) well-defined mission performance parameters and cost objectives early in DDT&E.
- Assign highly capable personnel with applicable experience.
- Develop well-defined program plans based upon essential technical and management requirements to accomplish the mission. These program plans will be brief and concise and directive in nature to provide clear management direction and assessment without excess detail.
- Provide closely coupled contractor/Government working relationships including collocation of counterparts and task-sharing where effective.

- Develop specific contractual clauses that provide motivation to both contractor and Government to achieve the lowest cost consistent with excellence of performance and tight schedule requirements.
- Operate critical change control under strict criteria (is it functionally necessary — it is cost-effective) for accept/reject decision.
- Apply management systems responsible to the needs of contractor/Government and provide timely visibility into potential problem areas to avoid vulnerability to unplanned cost or schedule delays.
- Procure "Buy" items, particularly off-the-shelf material and subsystems components, from lowest-cost, technically capable suppliers.

Features of several of the more crucial management systems are presented below:

- Performance Measurement System (PMS)
  The MDAC PMS is an on-line approved system currently in use on the Air Force ACE program, the Army SAFEGUARD/Spartan and Site Defense programs, and the Navy Harpoon program. Our experiences show that a low-cost and effective PMS requires a realistic WBS structure, ability to selectively apply BCWS/BCWP and variance analyses, ability to adjust the levels of reporting and control to the magnitude of the cost risk represented by the WBS elements, and to provide management reports at meaningful time intervals.
- Cost-Per-Flight (CPF) Management Controls
  CPF controls have been developed that are closely integrated with the PMS and the change control system. Based upon MDAC's life-cycle-cost-modeling technology, CPF provides cost goals (targets) throughout the WBS. CPF provides continuing predictive capability for total cost, impact assessment, and variance projections against lower-level WBS element cost targets as well as total project cost. Multidiscipline specialists work closely together to develop the cost estimates leading to the CPF targets. The task and functional managers are accountable for successful attainment of CPF goals, including development of the options and trade analyses necessary to

recover should unfavorable variances appear. One of the keys to achieving low-cost objectives is to understand the impact of decisions on program costs — a primary purpose of CPF.

- Configuration and Change Management (CM)

  The goal of CM is to effectively define contract item configuration and to manage change. On Space Tug, once a configuration is defined, it is imperative that strict criteria, by which a proposed change can be evaluated and accepted/rejected rapidly and effectively, be established. The configuration control board chaired by the program manager will use the CPF analysis to know the impact of changes against the CPF targets and the cost budgets. There is a corollary to the use of strict change criteria which implies that to avoid unnecessary costs, the mission requirements are well defined and the design team can design it right the first time to minimize change.

- Information Management (IM)

  The most effective as well as lowest-cost IM system makes maximum use of informal direct communication between designated contractor/Government counterparts for daily decision-making. This informal interchange is backed up by the formal contractual reporting system, which provides documentation of the key data and decision/action items for historical reference. The contracted data procurement document (DRD) and data requirements list (DRL) will make maximum use of internal data whever possible. In addition, MDAC's accessioning and deferred delivery methods will offer the customer up-to-date information on available internal documentation while minimizing the need for routine submission of data.

- Procurement Management

  MDAC's approach to make-or-buy, source selection, and procurement is to make use of existing proven industry capabilities while maintaining focus on the CPF targets. CPF targets are passed on to subcontractors and suppliers with appropriate contract incentives. Supplier reports are integrated into our PMS and CPF project reviews with a minimum of reprocessing. In accord with our internal information management system, the customer will have direct access to subcontractor/supplier data.

- Engineering Management

  MDAC's design team has extensive and successful cryogenic launch vehicle experience. A single organization will perform analyses, integration, and design tasks supported by functional specialists, as required (tooling, manufacturing, quality, test, logistics, etc) who are involved from project inception. Supporting this multi-discipline team approach is the recommendation for collocating contractor/customer/supplier representatives to encourage face-to-face daily dialogue. Cost-per-flight targets are assigned down to the lowest practical level of the WBS, and the design team will have specific Design-to-Cost (DTC) training. As the design concept evolves, senior engineers will be part of the team that will review the mission requirements, the design requirements, the detailed specifications, and the design drawings to ensure a thorough evaluation of alternatives to emphasize low-life-cycle costs, standard parts, and off-the-shelf hardware. Critical technical performance parameters, e.g., CPF, are selected for status reporting to provide most-meaningful technical progress assessment. Parameters are tracked by time-dependent trend data or single-point events and are measured by analysis or test with variances reported in time for corrective action with minimum cost/schedule impact. In addition to the above, the Engineering and the Manufacturing releases are closely coordinated (jointly signed off) before release to ensure full understanding and communication of each others' requirements and intentions.

In summary, application of MDAC's cost-awareness/cost-avoidance philosophy will enable Space Tug to avoid unnecessary material and labor costs. We will:

A. Understand the essential mission and program requirements, specifically:
   1. Technical
   2. Management
   3. Cost
B. Design and manage to meet the essential life-cycle requirements and the CPF targets
C. Test to verify design but minimize test hardware requirements and testing activities.

5.9 SUPPORTING RESEARCH AND TECHNOLOGY SUMMARY (SR&T)

The SR&T requirements for Option 1 are shown in Table 5-11. Because there is high emphasis on low DDT&E associated with this option, very little SR&T has been identified.

The first item, development of potential hazard/failure detection techniques, relates to safety and is applicable to any Tug program, regardless of funding constraints. The second item relates to establishing basic data required to develop an effective thermal control system.

The SR&T for this option is equal to approximately 0.4 percent of total DDT&E.

5.10 RISK ASSESSMENT SUMMARY PROGRAM OPTION 1

The Space Tug project is in the early stages of program definition (Phase A). We are confident that, as definition of the hardware, software, and programmatics evolves, the risk values identified will diminish significantly. Therefore, we assess Program Option 1 as a moderately low-risk program.

On a scale of 0 to 10 (i.e., low risk to high risk, respectively) the average life-cycle risk values for Option 1 are: 2.4 for Cost; 1.9 for Schedule; and 2.4 for Technical performance. (Refer to Table 5-12.) These relatively low-risk values mean that the multidiscipline team of experts who have assessed the uncertainties in accomplishing the cost, schedule, and technical objectives and assigned the risk values have a moderately high degree of confidence that all objectives will be met for every WBS element in every phase of the project. Their collective judgments are based on the following:

A. Specifications on similar hardware and software items are available;
B. The hardware and software subsystems/components are well within the state of the art and (as a minimum) prototype items have been produced (in many cases off-the-shelf hardware is selected);
C. The estimating ground rules and assumptions were generally adequate although subject to some question; and

Table 5-11

SR&T SUMMARY - OPTION 1

WBS Element/Option	Technology Requirement	Cost ($M)	Time (Years)	Required Start Time
320-03 Vehicle Main Stage	Develop potential hazard/failure detection techniques	0.75	1.5	CY 2/75
320-03-02 Thermal Control Radiation Barrier and Purge Bag	Establish thermal performance, material properties and purge bag material and fabrication techniques	0.09	1.0	9/75
	Total	0.84		

Table 5-12

RISK ASSESSMENT SUMMARY PROGRAM OPTION 1

Risk Values (0 = Low; 10 = High Risk)

Project Phase	Risk Area		
	Cost	Schedule	Technical
DDT&E	2.9	1.8	2.7
PROD	2.2	1.6	2.4
OPNS	2.1	2.2	2.1
Average Life Cycle Risk Values	2.4	1.9	2.4

D. The data have generally been obtained from reliable sources.

NOTE: A full description of our risk assessment methodology and the detailed data sheets are contained in Section 9 of Volume 8.

In the risk assessment data sheets (Table 5-13) accompanying this summary, a narrative risk assessment is provided for all cost, schedule, and technical risk values of five or greater. It is significant that most of the moderate-to-high risk values shown are due to the preliminary or incomplete nature of the information available and are not due to technical or capability uncertainties. Therefore, as further definition of the program evolves, we can expect a corresponding decrease in all risk values.

Table 5-13

RISK ASSESSMENT DATA SHEET

Program Option 1, DDT&E Phase
Page 1 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Risk Values of 5 or Greater)
320-01 Project Management	3	1	1	
320-02 Systems Engr & Integration	3	1	1	
320-03 Vehicle Main Stage				
-01 Structures	2	2	2	
-02 Thermal Control	2	2	4	
-03 Avionics	2	1	3	
-04 Propulsion	2	1	3	
-05 Orbiter Interface	5	1	6	Prelim Spec Definition (Cost); Prelim Abort Data & Analysis (Tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	2	2	5	Pressure/Chemical/Heat Hazards (Tech)
320-04 Vehicle Auxiliary Stage	5	GFE	1	Mfg Start-up on Poseidon Questionable (Cost)
320-05 Logistics	3	3	1	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 1, DDT&E Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Risk Values of 5 or Greater)
320-06 Facilities	5	3	1	Prelim Info Only (Cost)
320-07 Ground Support Equipment	3	2	5	Prelim Info for GSE Software (Tech)
320-08 Vehicle Test	3	2	4	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	2	3	2	
320-12 Flight Opns - ETR	2	3	2	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	44	27	41	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	2.9	1.8	2.7	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 1, PROD Phase
Page 1 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	2	1	1	
320-02 Systems Engr & Integration	2	1	1	
320-03 Vehicle Main Stage				
-01 Structures	2	2	4	
-02 Thermal Control	2	2	1	
-03 Avionics	2	1	3	
-04 Propulsion	2	1	3	
-05 Orbiter Interface	3	1	5	Prelim Spec Definition (Tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	2	2	5	Pressure/Chemical/Heat Hazards (Tech)
320-04 Vehicle Auxiliary Stage	5	GFE	GFE	Mfg Start-up on Poseidon Questionable (Cost)
320-05 Logistics	2	3	1	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 1, PROD Phase
Page 2 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-06 Facilities	1	3	1	
320-07 Ground Support Equipment	1	2	4	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	-	-	-	
320-12 Flight Opns - ETR	-	-	-	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	26	19	29	
MAXIMUM SCORE POSSIBLE	120	120	120	
RISK VALUE (0-10 SCALE)	2.2	1.6	2.4	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 1, OPNS Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	-	-	-	
320-02 Systems Engr & Integration	-	-	-	
320-03 Vehicle Main Stage				
-01 Structures	1	2	1	
-02 Thermal Control	1	2	1	
-03 Avionics	1	1	2	
-04 Propulsion	1	1	3	
-05 Orbiter Interface	1	1	1	
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	N/A	N/A	N/A	
320-04 Vehicle Auxiliary Stage	1	GFE	1	
320-05 Logistics	2	3	1	

Table 5-13

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 1, OPNS Phase
Page 2 of 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-06 Facilities	3	3	1	
320-07 Ground Support Equipment	2	2	1	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	3	3	4	
320-10 Launch Opns - ETR	3	3	4	
320-11 Flight Opns - WTR	3	3	4	
320-12 Flight Opns - ETR	3	3	4	
320-13 Refurb & Integration - WTR	3	3	2	
320-14 Refurb & Integration - ETR	3	3	2	
TOTAL SCORE	31	33	32	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	2.1	2.2	2.1	

Section 6
SENSITIVITY STUDIES

6.1 TWO-YEAR IOC DELAY

The objective of this analysis was to determine the programmatic sensitivity of Option 1 to a two-year IOC delay from December 31, 1979 to December 31, 1981. Two cases were examined to determine the impacts on costs and funding requirements during DDT&E, production, and operations. A primary goal was to evaluate techniques for reducing peak annual funding requirements for the baseline option without excessive impact on DDT&E costs. Case 1 represented a condition in which an attempt was made to take full advantage of the two-year delay during the DDT&E and early production phase by holding to the baseline option ATP, October 1975. Case 2 represented a condition in which the ATP was slipped to October 1976, reducing the stretchout of the DDT&E and initial production phases. Also, due to the IOC delay and in consideration of a gradual buildup in operational flight activity the first two years after IOC, a total of 26 fewer flights are flown by Cases 1 and 2 compared to the baseline option. This results in a reduction of $23.4 million in operating costs for these cases.

Figure 6-1 presents the planned project summary schedule for Case 1, and reflects the lengthened activity spans and milestone adjustments. Stretchout of the manufacturing operations results in a vehicle delivery rate of 2.8 per year with a single shift, five-day work week. Case 2, with the ATP shifted to October 1976, would provide a more moderate stretchout, the vehicle delivery rate being 3.2 per year based on a single-shift operation. The baseline option due to schedule constraints requires a two-shift activity in vehicle manufacturing. The delivery rate is four vehicles per year.

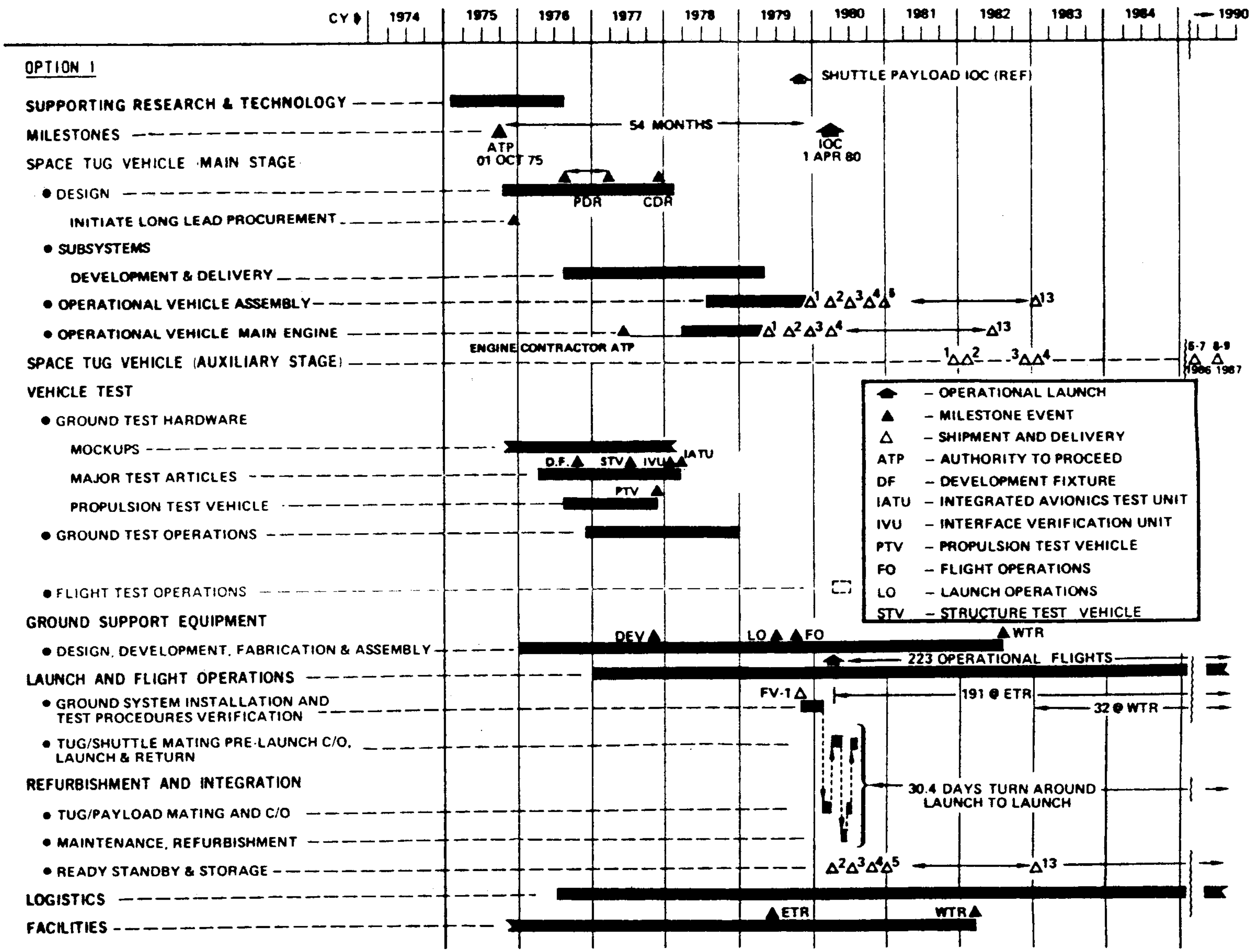
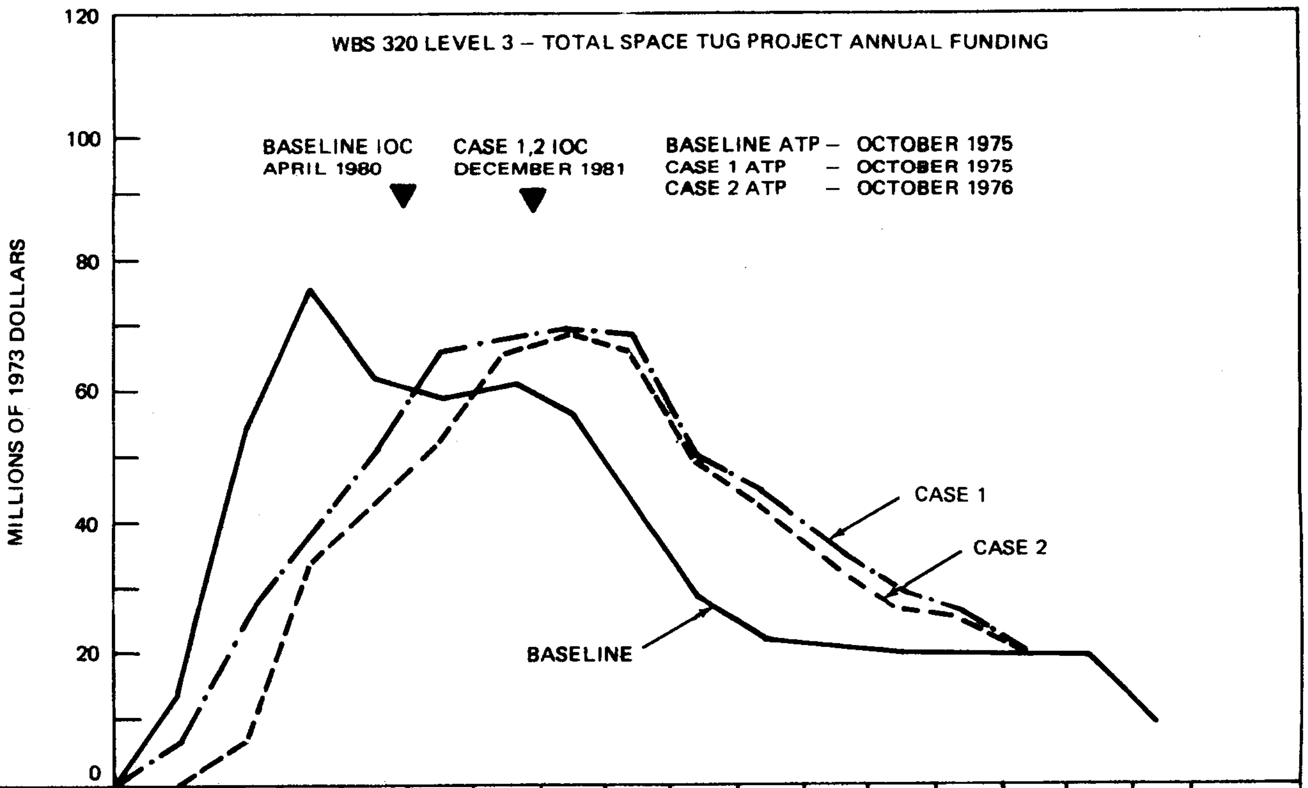


Figure 6-1. Space Tug Project Schedule

Figure 6-2 presents a summary of the impact of the delayed IOC on total project costs and funding for Cases 1 and 2 in comparison with the baseline Option 1. Peak annual funding is reduced to $69.4 million for Case 1 and $68.6 million for Case 2, both occurring in Fiscal Year 1982. This represents a reduction of approximately 10 percent from the baseline peak funding ($76.7 million in Fiscal 1978). Examination of the impact on total project costs indicates that Case 2 is a lower-cost project than the baseline and significantly lower than Case 1. The primary cost reduction stems from lower manufacturing costs associated with the shift differential and lower operating cost due to the reduction in the flight schedule from the baseline.

Table 6-1 provides a comparative tabulation of costs and funding by project phase. Supporting data and detailed discussion of the cost and funding considerations for this option sensitivity analysis are contained in Volume 8, Book 1, Section 8.



GOVT FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
BASELINE	12.9	54.0	76.7	62.0	58.0	60.6	55.8	42.2	27.5	21.8	20.6	19.4	19.0	19.0	18.8	9.1	577.5
CASE 1	6.5	25.0	37.5	50.0	66.0	67.7	69.4	68.0	49.0	44.0	36.0	29.0	25.4	19.0	18.8	9.5	620.8
CASE 2		6.0	33.4	42.0	51.4	65.2	68.6	65.4	48.0	42.3	33.7	25.6	25.0	19.0	18.8	9.5	553.9

Figure 6-2. Option 1, Two-Year IOC Delay, Impact on Total Project Funding

Table 6-1

OPTION 1
2 YEAR IOC DELAY - IMPACT ON TOTAL PROJECT FUNDING AND COST
WBS 320, LEVEL 3 - TOTAL SPACE TUG PROJECT
ANNUAL FUNDING

Govt. FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
Baseline																	
DDT&E	12.9	53.1	68.5	40.6	17.1	4.4	0.1										197.1
Production		0.9	8.2	21.4	32.1	41.0	39.8	23.2	8.5	2.8	1.6	0.4					179.6
Operations					8.8	15.2	15.9	19.0	19.0	19.0	19.0	19.0	19.0	19.0	18.8	9.1	200.8
Total	12.9	54.0	76.7	62.0	58.0	60.6	55.8	42.2	27.5	21.8	20.6	19.4	19.0	19.0	18.8	9.1	577.5
Case 1																	
DDT&E	6.5	20.0	25.0	35.0	50.0	35.0	30.0	25.0	5.0								231.5
Production		5.0	12.5	15.0	16.0	30.0	25.0	25.0	25.0	25.0	17.0	10.0	6.4				211.9
Operations						2.7	14.4	18.0	19.0	19.0	19.0	19.0	19.0	19.0	18.8	9.5	177.4
Total	6.5	25.0	37.5	50.0	66.0	67.7	69.4	68.0	49.0	44.0	36.0	29.0	25.4	19.0	18.8	9.5	620.8
Case 2																	
DDT&E		6.0	23.0	30.0	37.0	45.0	36.0	22.0	5.0								204.0
Production			10.4	12.0	14.4	17.8	18.2	25.4	24.0	23.3	14.7	6.6	6.0				172.5
Operations						2.7	14.4	18.0	19.0	19.0	19.0	19.0	19.0	19.0	18.8	9.5	177.4
Total		6.0	33.4	42.0	51.4	65.2	68.6	65.4	48.0	42.3	33.7	25.6	25.0	19.0	18.8	9.5	553.9

6.2 DDT&E EFFECTS FOR MISSION DURATION GREATER THAN 36 HOURS

A sensitivity study was performed to determine the impact on the Option 1 vehicle of extending its mission duration capability from 1-1/2 days to 6 days. The impact was assessed for the following two cases:

Case 1 - The degradation in geosynchronous deployment capability with extended mission duration was determined for no substitutions in the Option 1 subsystems. The only changes made were to increase the number of batteries and ACPS propellant capacity commensure with the increasing power and attitude stabilization requirements. No additional DDT&E costs were assumed for these changes.

Case 2 - For this case, subsystems were selectively changed as a function of extended duration wherever the geosynchronous deployment capability fell below the initial 36-hour value. The difference in DDT&E costs associated with these subsystem substitutions were determined for various mission durations.

The 36-hour deployment mission profile was used for this analysis. Extensions in mission duration were assumed to occur after injection into synchronous orbit and prior to payload deployment. All other aspects of the mission profile were held constant. The results of the analysis indicated that the Option 1 deployment capability drops rapidly with increased mission duration if no subsystem changes are made (Case 1). This rapid dropoff is primarily due to the additional batteries required to meet increasing power demands. If the performance is not allowed to drop below the baseline 36-hour capability for a six-day mission (Case 2), the following subsystem changes are required, which increased the Option 1 DDT&E cost by about $20M:

A. Pressurization System - Change from ambient helium to cold stored, heated helium for tank repressurization.

B. Power System - Change from batteries to current-design fuel cells.

C. Thermal Control System - Add multilayer insulation.

D. Attitude Control System - Change from blowdown monopropellant hydrazine to pressurized storable bipropellant.

6.2.1 Performance Impact

The total impact of extended mission duration on the Option 1 deployment capability is shown in Figure 6-3. This impact is a composite of the individual subsystem impacts that were previously discussed. For the case where no subsystem changes are made other than to increase the ACPS consumables and number of batteries as required (Case 1), the performance drops rapidly as the on-orbit time is increased beyond 36 hours. The negative slope of this curve represents the effect of increased consumables, viz., boiloff and ACPS propellants. The discontinuities represent the impact of battery additions and an ACPS tank change.

The dashed curve in Figure 6-3 shows the Option 1 performance for the case where subsystem changes are allowed to preclude performance loss for the extended mission durations. The required subsystem change is a function of the desired mission duration. For example, the baseline Option 1 vehicle is power limited, and to extend its on-orbit time capability from 1-1/2 to about 2-1/2 days requires the addition of three batteries. This results in an increase in inert weight of 280 pounds. Several subsystem modifications are available to offset this increase in burnout weight. However, the most cost-effective is to replace the ambient helium repressurization system with a heated helium repressurization system. The heated helium repressurization system is about 370 pounds lighter than the ambient helium system, and the difference in DDT&E cost is about $1.06M.

For on-orbit times of greater than 2-1/2 days, the next recommended subsystem change is to replace the battery power supply with a current, e.g., General Electric, fuel cell. This substitution would result in DDT&E cost difference of about $9.09M.

The addition of MLI is required for design on-orbit times in excess of 4-1/2 days. This change would result in an acrease in DDT&E cost of about $1.74M. As previously noted in the thermal control system discussion, the performance crossover between the radiation-barrier only and MLI system occurs at about 2 days on-orbit time. The reason for not recommending the addition of MLI at that duration is because it did not "buy back" enough

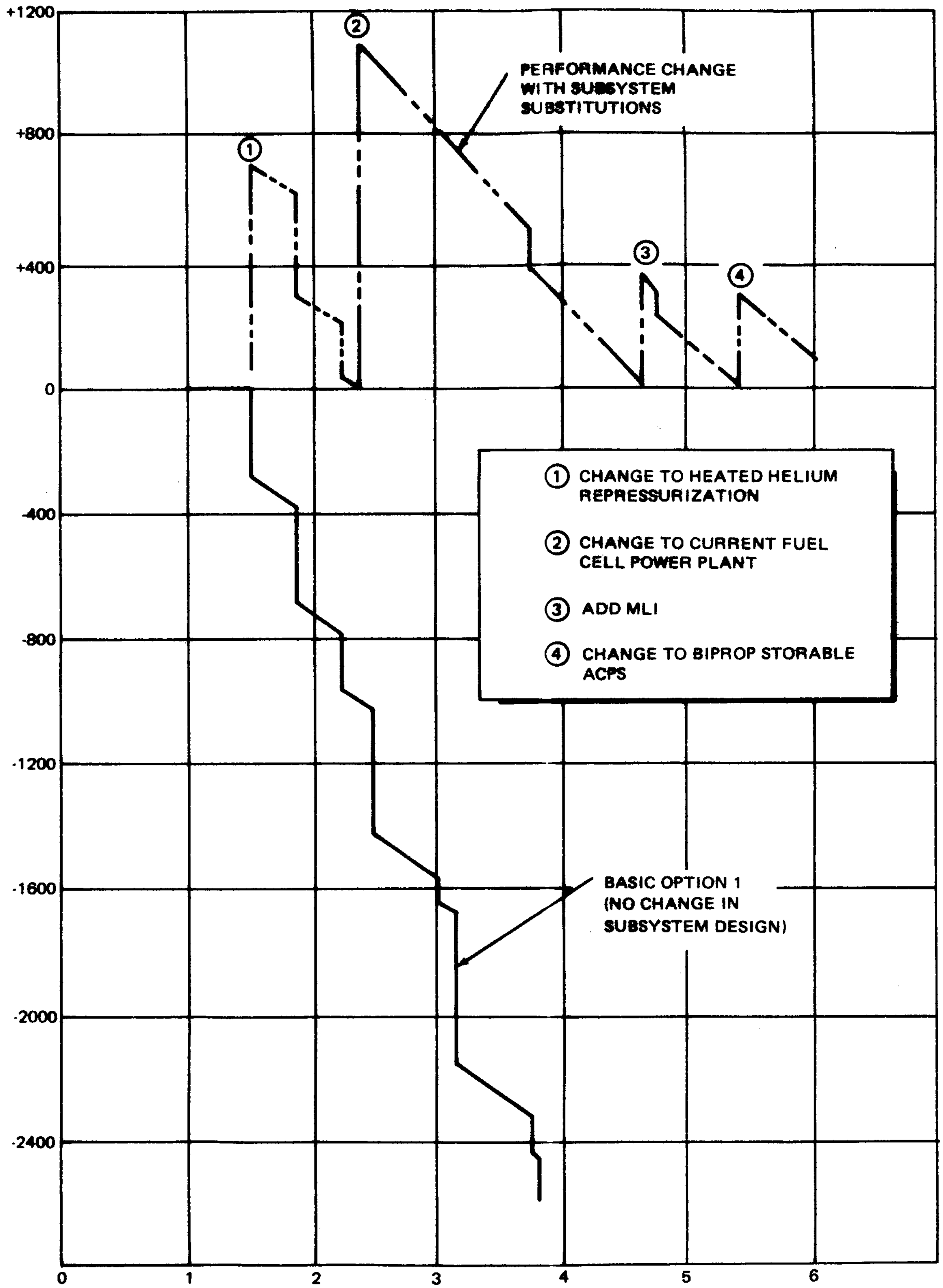


Figure 6-3. Option 1 Sensitivity to Increased Mission Duration

performance to offset the additional battery weight. Therefore, the fuel cell substitution was required before the MLI substitution for that design duration.

Finally, another subsystem substitution is required for mission duration in excess of about 5-1/2 days to maintain the Option 1 performance level out to 6 days. The monopropellant hydrazine ACPS would have to be changed to the higher-performing bipropellant storable ACPS. This would increase the DDT&E costs by about $6.6M.

6.2.2 DDT&E Cost Impact

The effect of the subsystem changes on the DDT&E costs are summarized in Table 6-1. These costs were based on values at WBS Levels 5, 6, and 7. They include assembly, integration, and checkout through system Level 4; systems engineering and integration; and project management.

The flight operations costs shown in Table 6-2 indicate a small increase in DDT&E cost of approximately $0.6M for an additional 36 hours of mission duration. This increase represents a 0.166 percent increase per hour of

Table 6-1

SUBSYSTEM DDT&E COSTS FOR INCREASED MISSION DURATION

Option 1 Subsystem	Uprated Subsystem	ΔDDT&E
Ambient He Repressurization DDT&E = 3.321 $M	Heated He Repressurization DDT&E = 4.377 $M	1.056 $M
AGENA Technology AG-Zn Batteries DDT&E = 0.197 $M	G.E. Fuel Cells DDT&E = 9.285 $M	9.088 $M
Radiation-Barrier DDT&E = 1.210 $M	Multilayer Insulation DDT&E = 2.950 $M	1.740 $M
Blowdown N_2Hy DDT&E = 9.734 $M	N_2Oy/MMH DDT&E = 16.329 $M	6.595 $M

Table 6-2

FLIGHT OPERATION COSTS SENSITIVITY TO INCREASE MISSION DURATION

Mission Time (hours)	36	72	144
DDT&E ($M)	9.98	10.58	11.72
Δ Costs ($M)	0	0.60	1.74
Percent Increase in DDT&E Costs/Hour	0	0.166	0.162

mission duration. The main reason these DDT&E flight operations costs increased with mission duration is that the simulation activities require additional man-hours and computer time. This simulation task includes software development and crew training.

The cumulative difference in DDT&E costs including the subsystem changes and flight operations impact is summarized in Figure 6-4 for varying vehicle mission durations up to 6 days. The increase in DDT&E costs between the indicated subsystem changes reflects the increase in flight operation DDT&E as a function of mission duration.

6.3 IMPACT TO PROVIDE 300-WATT POWER TO PAYLOAD

The purpose of this sensitivity study was to determine the impact of adding the capability to provide the payload with 300 watts of continuous power.

The Option 1 primary power system utilizes batteries. Therefore, it was felt the minimum impact would be obtained by adding more battery power rather than changing to a different power source such as a fuel cell.

The approach was to determine the impact (cost and weight) of providing additional battery power. If it were determined that this approach created an undue weight penalty, then alternative systems would be assessed. As will be shown, the weight penalty was not exorbitant, and alternate systems were dropped from further consideration.

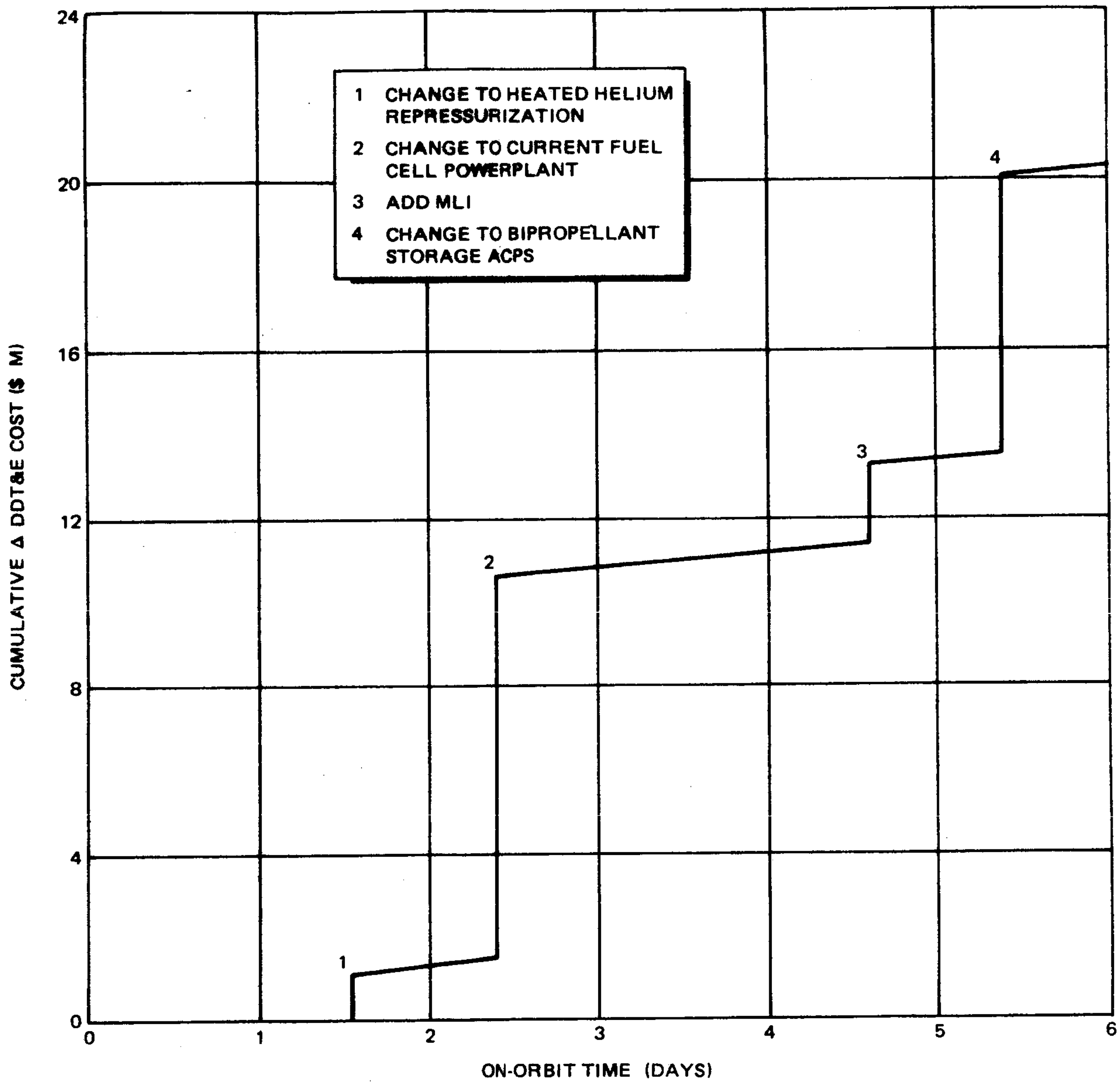


Figure 6-4. Option 1 DDT & E Cost Sensitivity to Increased Mission Duration

The current Option 1 power system contains two 775-amp-hr batteries, based on Agena design. It was determined that substituting three 650-amp-hr Agena-based design batteries provided ample additional power to supply the payload 300 watts continuously not only for the 11.9-hr deployment time, but throughout a full mission, should a sortie mission be required. Table 6-3 summarizes the weight and cost penalties associated with this substitution.

Because the batteries differ only in unit size and are based on the same state-of-the-art design, no additional DDT&E cost could be identified. However, the procurement cost for three 650-amp-hr batteries was estimated to be some $11,500 per vehicle higher than the cost of two 775-amp-hr batteries used in the current Option 1 design.

Table 6-3

POWER SYSTEM SENSITIVITY TO PAYLOAD POWER REQUIREMENTS PROGRAM OPTION 1

Basic Program Option - no payload power	
Two 775-amp/hr batteries based on Agena design	430 lb
300-Watt Payload Requirement for 11.9 hr	
Three 650-amp/hr batteries based on Agena design	534 lb
300 Watt Payload Requirement for Full Mission Duration	
Three 650-amp/hr batteries based on Agena design	534 lb
Δ Battery Weight	134 lb
Additional Mounts and Power Distribution Weight	20 lb
Total Penalty	154 lb
Equivalent Geo Sync Payload Weight	425 lb

Delta Program Cost

DDT&E	Production	Operation
0	$101,000	$1,087,000

6.4 SENSITIVITY STUDY SUMMARY

The balance of the sensitivity studies which are summarized in Figure 6.4-1 are discussed in detail in Volume 5.

SENSITIVITY RESULTS SUMMARY - OPTION 1

Sensitivity Area	Reference	Impact Delta (Reference): Cost ($ millions) TFCH	DDT&E	First Unit	Total OPN	Veh. Design: Inert Wt(lb)	P/L Del Wt.	Dev. Risk	Critical Tech. Areas
Autonomy	Level IV								
Level III			2.82	0.06	-19.03	2	- 5.4	None	None
Level II		5.0	18.06	1.37	-14.31	238	-643	Medium	Auto Mfn. & Mission Plan.
Level I		5.0	15.08	1.37	-19.52	238	-643	Low to med.	Auto. Nav.
0.97 Reliability	0.97/36								
0.97/72 hr.		0	0	0	-	0	0	None	None
0.97/142 hr.		0	3.4	0.46	-	26	- 70	None	None
6 Day Duration	36 Hour								
72 Hour		0	10.74	1.30	-	-700	+800	Low	None
144 Hour		1.0	11.88	1.41	-	-630	-200	Low	MLI
DOD Comm. Req.	NASA Req.	0	0.50	0.13	-	136	-367	Medium	High gain antenna
300$^{\omega}$ Power to Payload	0	0	0	0.01	0	154	-425	Low	None
Design Life (> 100)	20 Reuses	0	0	0	0	0	0	None	None
Rendezvous and Docking	None	5	6.59	0.61	-	188	-517	High	Sensor
Spin Stab. P/L Retrieval	W/O	0	0	0	0	0	0	None	None

Appendix A

OPTION 1A: REDUCED DDT&E COST SYSTEM

Program Option 1A is a revised version of the baseline Option 1 concept in which established guidelines, ground rules, or design concepts have been redefined in the interest of further reductions in DDT&E costs. In most instances the modifications to the baseline program Option 1 as incorporated into the Option 1A concept result in greater risk or deviations from the government directed program requirements. However, because of the great importance attached to minimizing DDT&E costs and to provide some insight into what further cost reductions might be realized through a relaxation of the basic program requirements, it is felt appropriate that these data be presented.

It should be noted that any departures from the pre-defined program requirements have been limited to those which were judged by MDAC to have minor consequences on the fundamental Tug program concept. Critical requirements, such as safety criteria, would not be compromised. The intent was to retain the basic framework of the program while identifying potential areas for development cost reductions. Further, these cost reductions have been restricted to those applicable only to DDT&E; similar reductions in production and operation costs are worthy of further study.

A.1 COST REDUCTION CONCEPTS

Table A-1 summarizes the cost reduction concepts by major program element. Also listed, for reference, is the approach taken on the baseline program, Option 1. The program impact, in terms of weight, performance, or programmatics and the net reduction in DDT&E cost and then provided. Table A-2 summarizes the DDT&E costs by WBS and presents a comparison of Options 1 and 1A. It is seen that the net DDT&E reduction is about $20M if all cost reduction concepts are incorporated.

Table A-1 (Page 1 of 6)

OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: STRUCTURES

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
5 Point Stage Support System	4 Point Support (ground ruled)	Reduction in fwd frame and structural shell loads; change fwd frame material from titanium to aluminum (ΔWt = -169 lb)	$-1.02M frame -1.02M shell $-2.04M
Constant Thickness Tankage Domes	Tapered domes used to satisfy minimum payload deployment requirement (3500 lb to geosynchronous orbit)	Heavier weight tankage (reduced performance capability) (ΔWt = +161 lb)	$-0.70M $-2.74M - .22M (assy and c/o) $-2.96M total structures

Table A-1 (Page 2 of 6)

OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: PROPULSION

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
Open Loop Propellant Utilization System	Closed loop system used to satisfy minimum payload deployment requirement (3500 lb to geosynchronous orbit)	Greater residual propellant quantities (ΔPayload = -600 lb)	\$ 0.35M (Open Loop System) -1.40M (Closed Loop System) \$-1.05M - .08M (assy & c/o) \$-1.13M total propulsion

Table A-1 (Page 3 of 6)

OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: AVIONICS

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
Utilize dual DIGS (computer + IMU) Systems. See attached block diagram	Central computer/data bus system + DIGS IMU	Eliminates central computer, 2 remote data processors, and command/control bus. Requires ground controlled redundancy management. (ΔWt = +68 lbs) (ΔPower = +73 watts: current power system adequate)	\$-1.46M Central computer - .47M Software \$-1.93M - .15M \$-2.08M total avionics

Table A-1 (Page 4 of 6)

OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: VEHICLE TEST

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
Eliminates pressure/pressure cycle qualification tests on main propellant tanks. (Presupposes adequate safety margins are demonstrated in development tests of identical hardware)	Conduct separate development and qualification pressure and pressure cycle tests. Note: development test hardware to be fabricated on production tooling.	Risk of requirement for additional test set if development test margins are inadequate.	$-0.53M hardware -0.11M test operations $-0.64M
Eliminate early flight test of cargo bay egress/ingress maneuvers using Interface Verification Unit (IVU)	IVU test currently planned.	Presents risk associated with performing maneuvers on-orbit for the first time with fueled, operational Tug and payload.	$-0.05M hardware -0.15M test operations $-0.20M
Reduce flight test quantities to one flight	Two flight tests currently planned.	Reduction in flight test data prior to full operational capability.	$-0.34M test operations $-1.18M total test

Table A-1 (Page 5 of 6)
OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: GROUND SUPPORT EQUIPMENT

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
Utilize Shuttle LPS at ETR and WTR for Tug checkout.	Shuttle LPS not available for Tug (ground rule)	Reduction in GSE requirements.	$-2.92M GSE
Integrate Payload Processing Facility (PPF) with Tug Processing Facility (TPF) at ETR. This is the approach now defined for WTR.	Independent PPF and TPF at ETR (ground rule)	Reduction in GSE requirements. Requires secure facility capability for Tug/payload processing.	$-1.25M GSE
Share Shuttle propellant loading/ pneumatics system	Independent Tug propellant loading/ pneumatics system (ground rule)	Requires integration of Shuttle and Tug operations.	$-2.96M GSE
Install Tug (with payload) into Shuttle at launch pad	Tug installation and checkout in MCF (ground rule)	Simplifies Tug ground operations; shortens Tug turnaround time and reduces man loading requirements	$-2.05M total GSE +1.06M GSE included in LPS utilization cost reduction $-0.99M net GSE reduction $-8.12M total GSE

Table A-1 (Page 6 of 6)

OPTION 1A: REDUCED DDT&E COST SYSTEM
PROGRAM ELEMENT: FLIGHT OPERATIONS

Cost Reduction Concept	Baseline Approach (Option 1)	Program Impact	DDT&E Cost Impact
Reduce flight operations software requirement through adaptation of existing software developed for DIGS.	New software development currently planned	Approximately 50% reduction in DDT&E Software	\$-1.1M DOD flight ops -1.3M NASA flight ops \$-2.4M total flight ops

Table A-2

DDT&E COST SUMMARY

WBS	Cost Element	Option 1	Option 1A
10	Project Management	$ 7.08M	$ 6.36M
20	System Engr & Integration	14.23	12.78
30	Vehicle Main Stage	102.17	96.00
40	Vehicle Auxiliary Stage	1.62	1.62
50	Logistics	3.02	3.02
60	Facilities	5.17	5.17
70	Ground Support Equipment	32.09	23.97
80	Vehicle Test	21.32	20.14
90	Launch Operations (WTR)	0.0	0.0
100	Launch Operations (ETR)	0.0	0.0
110	Flight Operations (NASA)	5.33	4.03
120	Flight Operations (DOD)	4.79	3.69
130	Refurbishment & Integration (WTR)	0.11	0.11
140	Refurbishment & Integration (ETR)	0.11	0.11
		$197.05M	$177.01M

The more substantial reductions were made in the vehicle main stage and ground support equipment. Most of the vehicle main stage cost reductions were the result of replacing components with heavier, less expensive alternates (with the exception of the change in stage support concept in which a system weight reduction was achieved). The GSE cost reductions were primarily the result of modifications to the ground ruled operational requirements as defined by the government.

A.2 WEIGHTS AND PERFORMANCE

A weight summary for the Option 1A configuration is presented in Table A-3. The net dry weight increase over the Option 1 configuration is only 40 lb (because of compensating component weight increases and reductions) while the total burnout weight has increased 215 lb. The large difference is the result of higher propellant residuals because of the open loop propellant utilization system.

All weights reflect direct adjustments to subsystem elements without resizing the vehicle to a new optimum propellant load. Resizing to the 65,000 lb ground launch weight limit would allow about a 100 lb improvement in payload capability but would preclude later upratings (to the Option 1 vehicle design) if such an approach should be desired.

Figure A-1 shows the performance capabilities of Option 1A compared with Option 1. Geosynchronous deployment capability for Option 1A is 550 lb less

Table A-3 (Page 1 of 2)

OPTION 1A
WEIGHT STATEMENT FOR DEPLOYMENT MISSION

STRUCTURE	2483		
FUEL TANK AND SUPPORTS		976	
LOX TANK AND SUPPORTS		318	
BODY STRUCTURE		906	
SHELL			670
SUPPORTS			236
THRUST STRUCTURE		106	
METEOROID PROTECTION		65	
PAYLOAD INTERFACE		112	
THERMAL PROTECTION	196		
FUEL TANK INSULATION		95	
LOX TANK INSULATION		15	
INSULATION PURGE		83	
CONTROL SYSTEM		3	
AVIONICS	1514		
DATA MANAGEMENT		290	
GUIDANCE AND CONTROL		132	
COMMUNICATION		152	
INSTRUMENTATION		215	
ELECTRICAL POWER SOURCE		(487)	
POWER DISTRIBUTION & CONTROL		94	
EQUIPMENT THERMAL CONTROL		144	
PROPULSION	1569		
MAIN ENGINE		293	
MAIN ENGINE SUPPORT		1137	
ACPS ENGINE		66	
ACPS ENGINE SUPPORT		73	
DRY WEIGHT	5762		
CONTINGENCY	576		
MARGIN	155		

Table A-3 (Page 2 of 2)

OPTION 1A
WEIGHT STATEMENT FOR DEPLOYMENT MISSION

TOTAL DRY WEIGHT	6493	
RESIDUALS		1062
BURNOUT WEIGHT	7555	
USEABLE PROPELLANT		51342
ACPS		236
MISC		416
INFLIGHT LOSSES	51994	
PAYLOAD	2971	
ORBITER LAUNCH WEIGHT	62,520	
ORBITER INTERFACE - CARGO BAY		1627
ORBITER INTERFACE - REMAINING		270
MISC		269
GROUND LAUNCH WEIGHT	64,686	

$$\text{Tug Mass Fraction} = \frac{\text{Useable Main Propellant}}{\text{Orbital Launch Weight - Payload}} = 0.862$$

PERFORMANCE CAPABILITY

CONFIGURATION OPTION 1A

W_{BO} 7555 lb

I_{SP} 441.8 Sec

(1) DEPLOY

(2) RETRIEVE

(3) ROUND TRIP

(4) EXPENDABLE

———— Option 1 (Ref.)

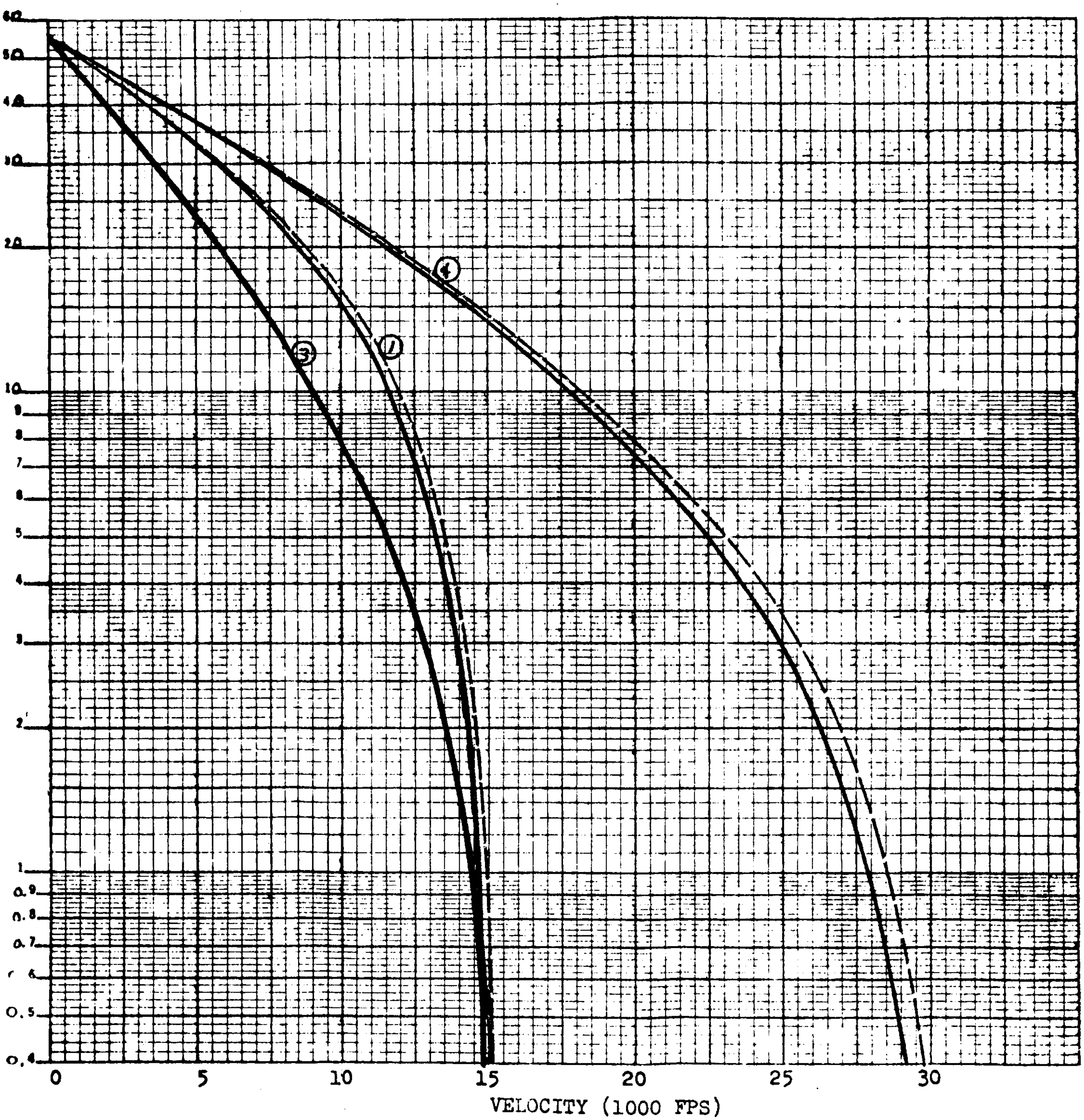


Figure A-1

than for the baseline concept. Summarized below are the geosynchronous payload capabilities for Option 1A.

Deployment:	2976 lb
Retrieval:	0
Round Trip:	878 lb

The flight requirements for this vehicle,bbased upon the Option 1 mission model, are summarized in Table A-4. All missions captured by the Option 1 vehicle are captured; however, because of its reduced performance, additional kick stages are required for planetary and some geosynchronous missions. These requirements can be most efficiently met with a small kick stage, such as Burner II. To accomplish the complete model, 23 flights (about 10%) more than Option 1 are required. This includes two additional vehicles to be operated in an expendable mode.

Table A-4

OPTION 1A
FLIGHT REQUIREMENTS

	80	81	82	83	84	85	86	87	88	89	90	Total	Total Option 1 (REF)
ETR													
NASA	3	8	3	7	6	6	4	8	6	7	6	64	87
DOD		4	11	13	11	6	10	9	12	6	10	92	89
NASA (EXP)					2		3	1		3	1	10	8
NASA (K/S-Large)			2		2		1	2				7	9
(K/S-Small)		2	3	4	3	4	2	4	3	3	2	30	-
DOD													
(K/S-Small)		2			2	2		3		1	2	12	-
TOTAL	3	16	19	24	26	18	20	27	21	20	21	215	193
WTR													
NASA	-	-	-	3	1	3	1	2	1	4	1	16	16
DOD	-	-	-	4	1	2	3	2	1	3	1	17	16
TOTAL	0	0	0	7	2	5	4	4	2	7	2	33	32
GRAND TOTAL	3	16	19	31	28	23	24	31	23	27	23	248	225
Reliability losses					1			1			1	3	3